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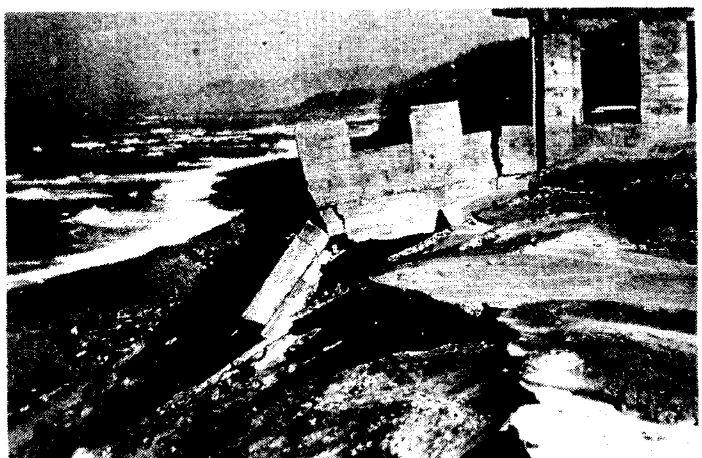
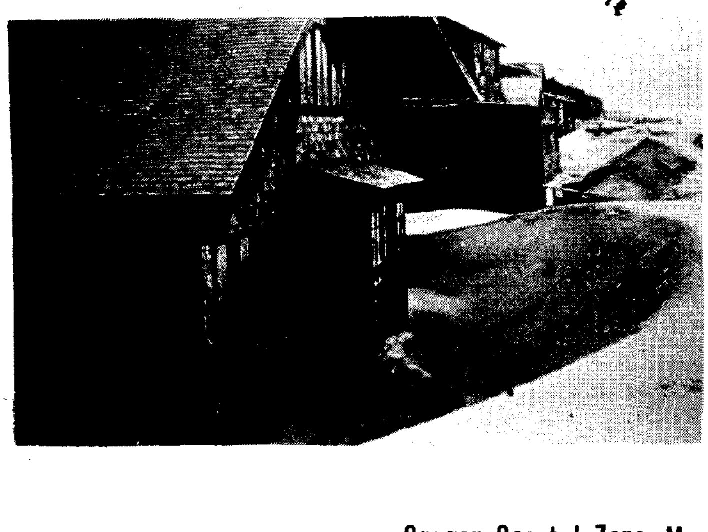
Coastal Zone Management Association

Physical Processes & Geologic Hazards On The Oregon Coast





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This report was prepared as part of a larger document addressing various beach and dune planning and management considerations and techniques. Other segments of the document and additional materials are:

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Cover design by Arlys Bernard, Newport, Oregon. Photos depict accretion at Clatsop Plains and erosion at Bay Ocean, Oregon.

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PHYSICAL PROCESSES AND GEOLOGIC HAZARDS ON THE OREGON COAST

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COASTAL ZONE
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PREFACE

The following report presents the results of an overview of beach and dune processes and erosion on the Oregon Coast. The study was conducted by Dr. Paul D. Komar, Associate Professor at Oregon State University, Corvallis under contract with the Oregon Coastal Zone Management Association, Inc. and with assistance from OCZMA's Beaches and Dunes Study Team composed of Carl Lindberg, Project Leader, Christianna Crook, Project Associate, Arlys Bernard, Project Secretary, Wilbur Ternyik, Project Coordinator and Kathy Fitzpatrick, Project Administrator. This report constitutes one element of an overall analysis of planning for and managing coastal beaches and dunes as required by Oregon's Beaches and Dunes Goal.

OCZMA extends special appreciation to Dr. Komar for the professional and timely manner in which this report was conducted. Additionally, OCZMA acknowledges the valuable review and comment made by the Beaches and Dunes Steering Committee composed of:

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I. INTRODUCTION

The coast of Oregon is made up of stretches of sandy beaches separated by rocky headlands jutting out into the sea (Figure 1). The major headlands such as Cape Blanco, Arago, Perpetua, Foulweather, Cascade Head, Lookout, Meares, Falcon and Tillamook Head are composed of hard basalt, resistant to wave attack. The stretches of beach vary in length from small pocket beaches nestled amongst the rocky headlands to the 50-mile long beach extending from Heceta Head south to Cape Arago near Coos Bay. The beaches are backed in part by sea cliffs cut into lithified sedimentary rocks, sandstones and mudstones, in all cases much less resistant than the basaltic headlands. In some areas the beaches are backed by foredunes consisting of loose sand; such foredune areas show little resistance to wave attack even when well vegetated. Sand spits, such as Coos, Siletz, Nestucca, Netarts, Bayocean and Nehalem, are almost all loose sand and have thus shown the greatest amounts of erosion when attacked by waves. Because sand spits are also particularly attractive building sites with views both of the ocean and bay, the most dramatic examples of erosion destruction have occurred there.

This report will examine particular erosion problems associated with the various sites on the Oregon coast and what can be done from a coastal planning viewpoint to minimize future problems. Sand spits and foredune erosion have presented the greatest erosion problems and therefore have been most extensively studied. The problems associated with dwelling construction in active foredune areas will be considered, followed by an examination of the longer-term erosion of the sedimentary sea cliffs, the erosion of which is important to communities such as Brookings, Bandon, Waldport, Newport, Lincoln City, Cannon Beach and many others.

Erosion of the Oregon coast cannot be understood properly without reference to the physical processes causing that erosion: the ocean waves, tides, nearshore currents, tsunami and winds. For that reason this report will begin with a discussion of these factors and what is known about physical processes on the Oregon coast. At the same time the sources of sand to the beaches and dunes and their general morphology will be examined.

II. COASTAL PROCESSES AND LAND FORMS

A. Beaches

Like most other continental beaches, the beaches of Oregon are composed mainly of quartz and feldspar sand grains derived originally from the weathering of granitic-type rocks. But within the beach sands are lesser amounts of dark heavy minerals such as hornblende, magnetite, augite, garnet and epidote, having shades of green, pink and black.

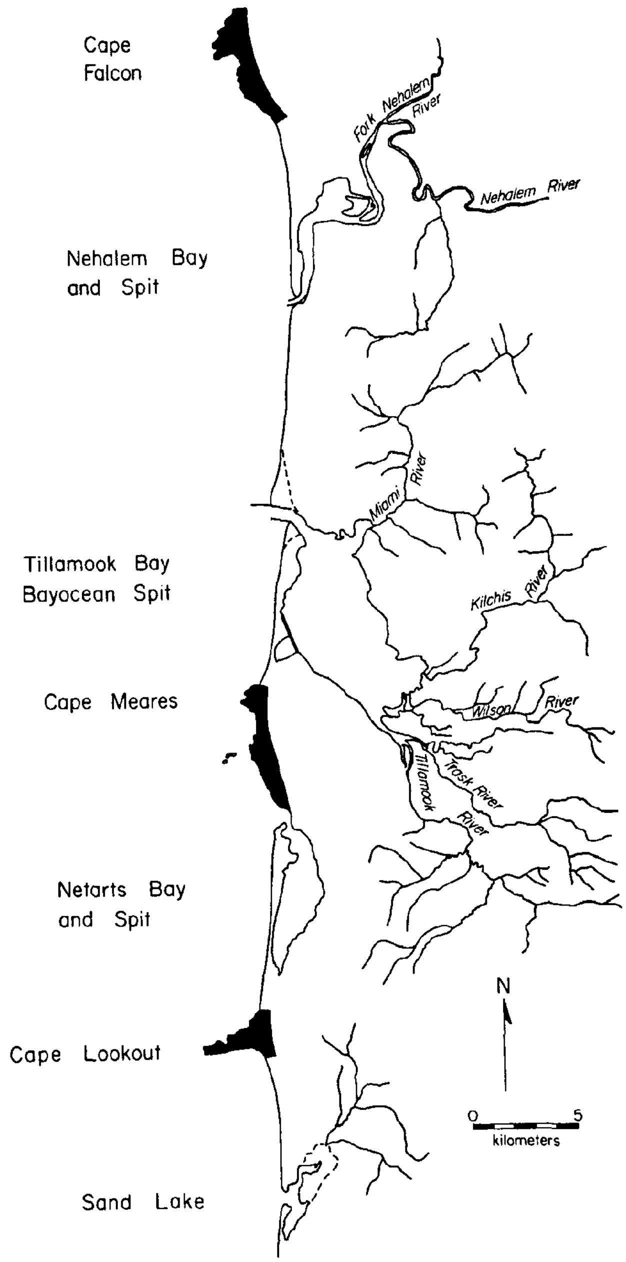


Figure 1. A portion of the north Oregon coast illustrating how it consists of a series of pocket beaches separated by pronounced rocky headlands.

At times these heavy minerals can become locally concentrated so that the beach sand appears greenish-black rather than having the tan color of the quartz and feldspar grains. In certain south Oregon beaches there are 'black sands' containing grains of gold, platinum and chromite, as well as the usual quartz, magnetite, etc. (Twenhofel, 1946). The gold and platinum attracted the attention of prospectors as early as 1852, and little now remains of those minerals in the black sands. The strategic mineral chromite was mined during World War II; although uneconomical to mine now, some chromite remains as a resource.

The beach sands generally have median grain diameters in the range 0.2 to 0.5 mm (fine to medium sand)(Wentworth, 1922), depending upon location. The overall grain size of the beach sand has important effects on the morphology of the beach and its response to erosion. In general, the coarser the beach sand the steeper its offshore slope (Komar, 1976, p. 303-8). Thus the beaches on Siletz Spit and at Gleneden Beach to the south, with a median grain size of about 0.4 mm, are much steeper (average slope - 3.1 degrees) than the more common finer grained beaches (0.2 to 0.3 mm) with average slopes of about 1.7 degrees (Figure 2). As shown by the study of Aquiler and Komar (1978) at two such beaches, a coarse-sand beach also has a higher rate of erosion when attacked by storm waves and a greater amount of total erosion. This in part explains, for example, why Siletz Spit in particular has suffered much erosion.

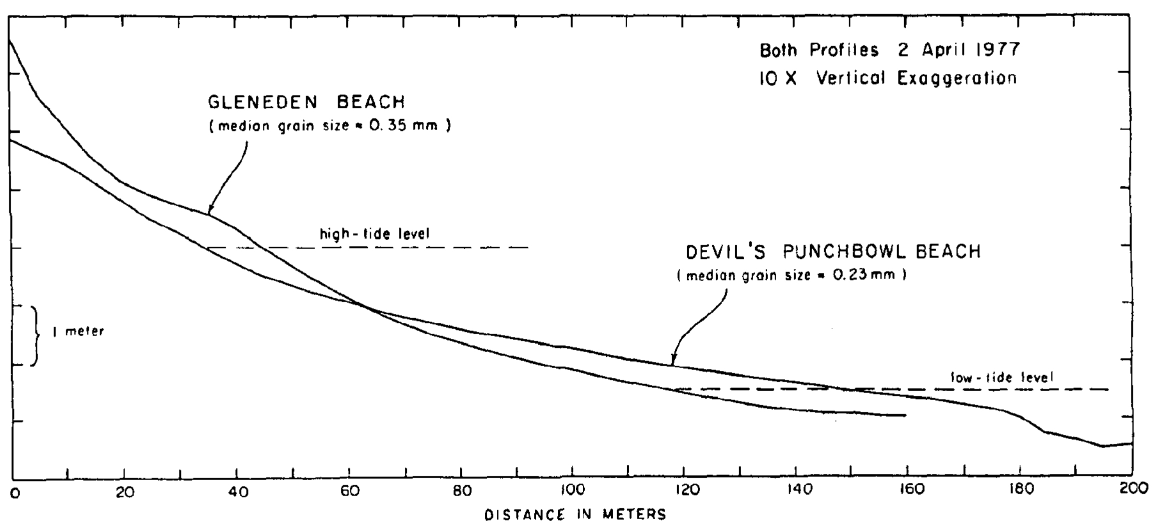


Figure 2. The effects of beach sand grain size on the profile, Gleneden Beach being much coarser and thus having a steeper slope than does the beach to the south of Devil's Punchbowl, Otter Rock.

Small pocket beaches in headland areas usually consist of basalt pebbles and cobbles (4 to 250 mm), the wave energy being too great for sand to remain on the beach. Continuing the trend of increasing beach slope with increasing grain size, these cobble beaches reach slopes of 5 to 25 degrees. Basaltic cobbles and pebbles are also found as a steep storm ridge along the flanks of headlands, backing the otherwise sandy beach (Figure 3). Such cobble ridges form a natural protective barrier from wave attack, important to such areas as Neahkahnie Beach south of Cape Falcon (Figure 3).

Figure 3. The beach at Neakahnie Beach with a steep cobble storm ridge of large rocks derived from the nearby basalt headland, backing an otherwise sandy beach. The cobble ridge offers protection to the coastal property.

B. Sources of Beach Sands

Management of beaches and coasts requires a knowledge of the natural sources and losses of beach sands. For example, if the principal source is sand brought to the coastal zone by rivers, then damming of the rivers would cut off much of that source, resulting in the long-term diminishing of the size of the beach and an increase in coastal erosion.

Such problems are best approached through a consideration of the budget of sediments (Bowen and Inman, 1966; Komar, 1976, Chapter 9). Such a budget involves assessing the sedimentary source contributions (credits) and losses (debits) and equating these to the net gain or loss (balance of sediments) for a given beach. The balance between gains and losses is reflected in local beach erosion or deposition. Table 1 summarizes the usual possible sources and losses of beach sands.

Table 1. The budget of littoral sediments

Credit	Debit	Balance
Longshore transport into area	Longshore transport out of area	Beach deposition or erosion
River transport	Wind transport out	
Sea cliff erosion	Offshore transport	
Onshore transport	Deposition in submarine canyons	
Biogenous deposition	Solution and abrasion	
Hydrogenous deposition	Mining	
Wind transport onto beach		
Beach nourishment		

Unfortunately, the sources and losses of sands to the Oregon beaches are generally only poorly known and usually cannot be quantitatively assessed. On most coasts, rivers are the principal sources, but this does not appear to be true for the majority of Oregon beaches. Many of our rivers pass through sizeable estuaries before reaching the ocean. The river sands are deposited in the estuaries rather than reaching the ocean beaches (Kulm and Byrne, 1966). This can be seen in Figure 4 which shows the areas of sand accumulation in Yaquina Bay and the sources of those sands. In that example the river sands do not reach the ocean beaches, and in fact beach sand is transported into the bay through the inlet so that the estuary represents a loss of beach sands in the budget of sediments. Although more study is needed of other bays and estuaries to determine whether they have similar sand depositional patterns, wide bays such as Coos, Siletz and Tillamook are probably all sinks of river sands so that those rivers do not provide sand to the beaches. Narrow river estuaries such as the Rogue, Umpqua and Siuslaw may be able to transport sand out onto the beaches. However, dredging activities in those estuaries may also remove them as sources of river sands to the beaches. Minor streams (without estuaries) do provide sands to the beaches, but in most cases they are quantitatively minor.

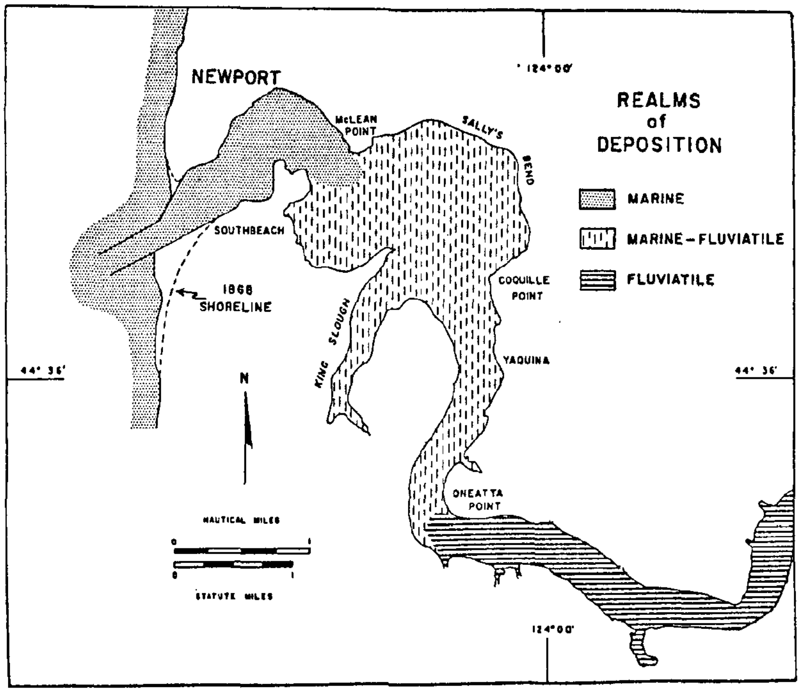


Figure 4. Areas of sand accumulation in Yaquina Bay indicating that the river sands deposit before reaching the ocean and that marine sands are transported through the inlet and also deposited in the bay (from Kulm and Byrne, 1966).

Of major importance to most Oregon beaches is the sand derived from sea cliff erosion. This is especially true where Pleistocene terrace sands form part of the sea cliffs. Removal of this source by the placement of riprap or sea walls (comparable to building a dam on a river) will lead to the long-term decrease in the size of the beach and an increase in coastal erosion.

At present the principal losses of beach sand are by winds blowing the sand inland to form dunes or by losses to the offshore deeper waters. The offshore losses are long-term; as the sand is abraded while on the beach, progressively decreasing in grain size, it may become sufficiently fine to be carried far enough offshore during a storm that it is unable to return to the beach.

Along most of the Oregon coast the sources and natural losses of beach sands are quantitatively small. For this reason, removal of beach sand by sand and gravel companies or others may have a major impact on the beach, this unnatural loss being a major factor in the total budget of sediments. An example of this was the impact of the removal of sand from the beach at Gleneden Beach south of Siletz Spit. An approximate budget of sand for the area is shown schematically in Figure 5. The principal source of sand to this beach has been from sea cliff erosion, estimated to contribute 16,000 cubic meters per year (that volume represents only sand coarse enough to remain on the beach, finer sediments being lost offshore). A study of the mineralogy and grain size of the sands shows that sand brought to the coast by the Siletz River does not contribute to the beach (Rea, 1975). The Salmon River and other small coastal streams contribute a minor amount. Prior to sand mining on the beach (1965 to 1971), the beach appears to have

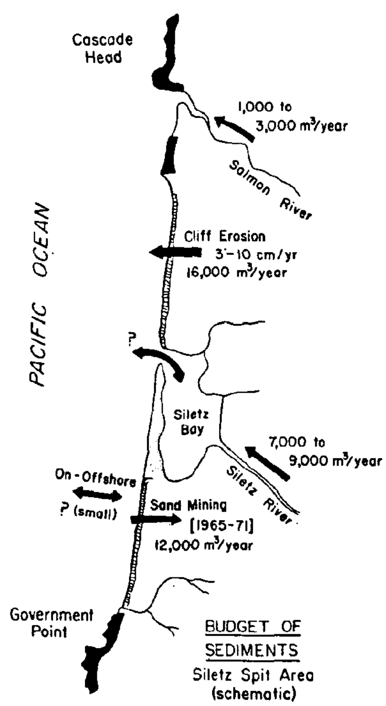


Figure 5. An approximate budget of beach sands for the stretch of coast fronting Lincoln City, south past Siletz Spit to Lincoln Beach. Shown are estimates of the sources and losses of sand from the beach, including that due to sand mining.

neither increased nor decreased in overall width over the years, indicating the natural losses of sand approximately balanced the gains from the sources; these losses must have been to the offshore, to the dunes on Siletz Spit, and some beach sand movement into Siletz Bay. The sand mining during the years 1965-71 removed an average of 12,000 cubic meters per year, an amount nearly the same as that contributed to the beach by sea cliff erosion. Presumably the natural losses remained the same, so that the sand mining represented a net loss of beach sands and a decrease in its total volume. Such a decrease would result in the progressive lessening of the beaches' ability to protect the coastal properties from erosion. As discussed in Section IV, the sand mining at Gleneden Beach was not the primary contributory factor in the recent erosion of Siletz Spit, but most certainly was an aggravating factor in causing increased amounts of erosion.

C. Dunes

Sand dunes, active or vegetated, occupy approximately 140 of Oregon's 310 miles of coast, or about 45 percent (Cooper, 1958; Lund, 1973). The largest area of active dunes with little or no vegetation extends for a distance of 55 miles between Coos Bay on the south to Heceta Head on the north (Figure 6). This strip averages about 2 miles in width, reaching a maximum width of 3 miles at Florence. A major portion of this active dune sheet lies in the Oregon Dunes Recreational Area, a division of the Siuslaw National Forest. A second area of important active dunes is present to the immediate north of Sand Lake on the northern coast.

There are extensive areas of older, well-vegetated dunes, commonly covered with forests of large trees and dense brush. The dune origin of the underlying sands is not always readily apparent; dune sands are best identified by the cross-stratification of sands exposed in roadcuts or other excavations. These vegetated dunes were formed during the Pleistocene Epoch, and are now perched on marine terraces well above sea level. They are common along the Oregon coast with the exception of Curry County south of Cape Blanco.

There are many problems concerning the management of these coastal dune areas. Particularly susceptible to erosion problems are the foredunes which immediately back many beaches. Such foredunes are usually active or only conditionally stabilized by dune grasses. Therefore the sands of the foredunes are often rapidly moved about by the strong coastal winds. In addition, because the foredunes are adjacent to beaches they may be eroded rapidly by waves.

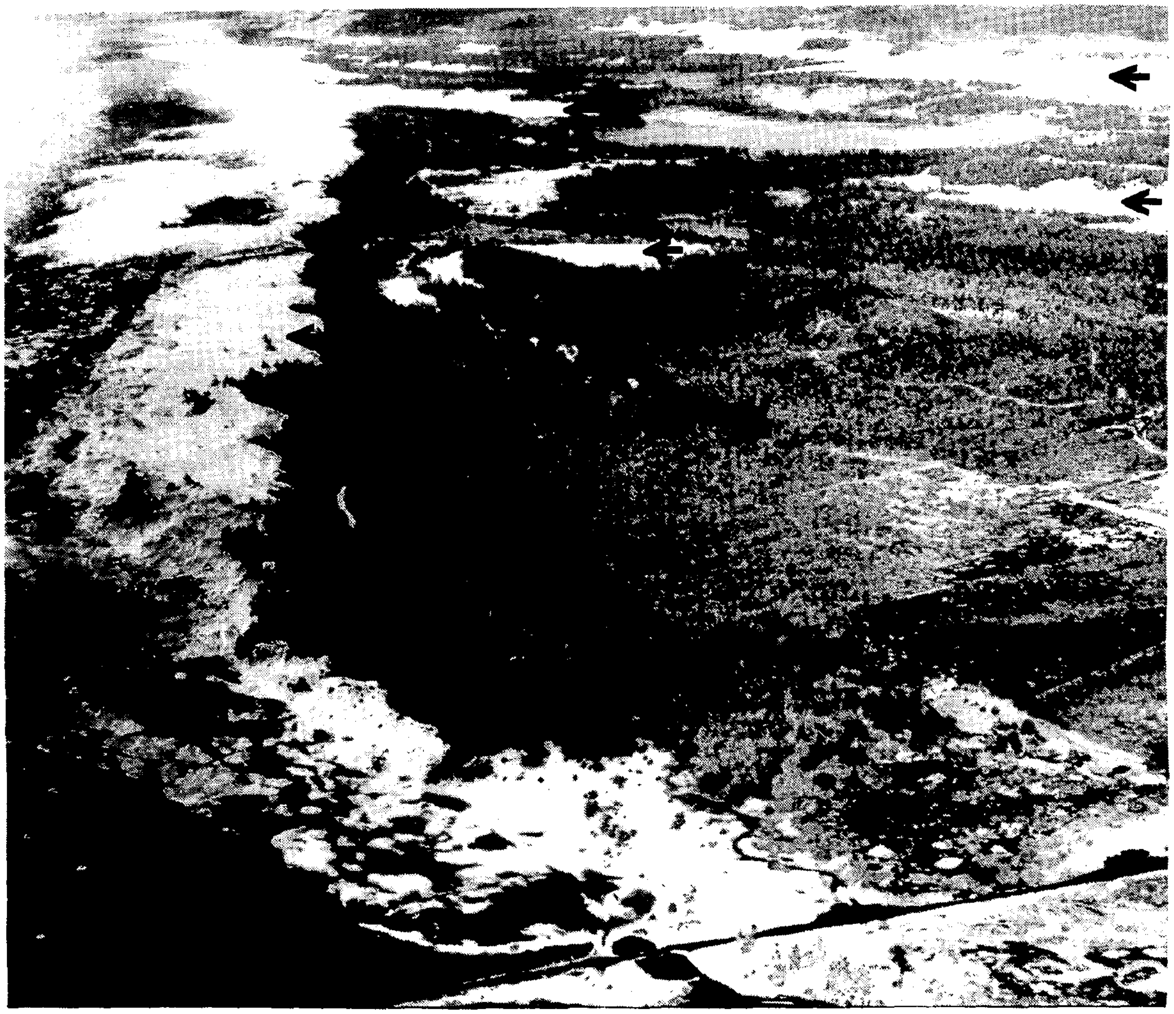


Figure 6. The active dune field of the Coos Bay dune sheet which stretches for some 55 miles along the mid-Oregon coast (photo courtesy of U.S. Army Corps of Engineers, Portland District).

D. Climate

Climate exerts a major influence on Oregon coastal beaches and dunes. In large part, rains govern the surface moisture in the dunes which in turn partly control whether the sands can be moved by winds. The direction and strength of the wind then determines the direction and rate of the resulting sand transport and dune migrations. The coastal winds are also important in wave generation and in the creation of nearshore currents along the beaches.

The climate of the Oregon coast is highly seasonable, more so than most other midlatitude coasts. During the winter months, storm systems move inland from the north Pacific bringing rains and a predominance of strong winds out of the south to southwest. The summer months are dry with milder winds, mainly from the north to northwest (Cooper, 1958).

Water runoffs in the coastal rivers and streams closely follow the seasonal variations in rainfall, discharges in the winter months being 30 to 50 times greater than during the summer (Figure 7). The Columbia River is the one exception to this discharge pattern in that it has two periods of maximum discharges, one during the winter due to the rains, and a second in May and June due to snow melt in the Cascade Mountains.

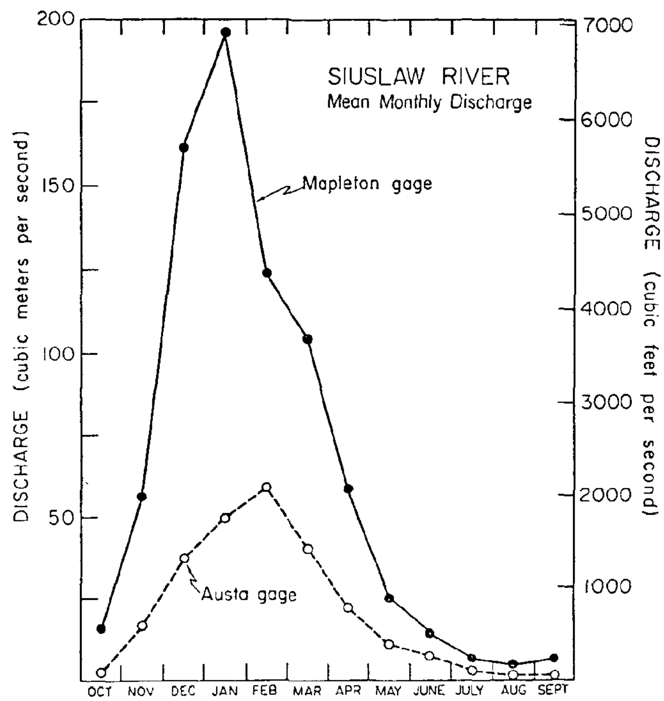


Figure 7. An example of the seasonality of river discharge with large winter discharges and negligible summer discharges, following the seasonality of rainfall.

E. Wave Conditions

Wave conditions along the coast of Oregon also follow a seasonal pattern in response to the parallel changes in weather patterns and wind speeds. This is to be expected as it is the wind that generates the waves; the greater the wind speed the higher the waves produced (Komar, 1976, Chapt. 4). Other factors in wave generation are the duration of the winds and the extent of water area (fetch) over which the winds blow. Not all waves reaching the Oregon coast come from local storm systems adjacent to the coast. An example is shown in Figure 8 from a storm that occurred over the north Pacific during 20-25 December 1972, a storm which generated 23-foot high breaking waves along the coast, resulting in much erosion, especially on Siletz Spit. It is seen that the winds that generated these exceptionally high waves blew across a major portion of the Pacific but were not particularly strong at the Oregon coast itself.

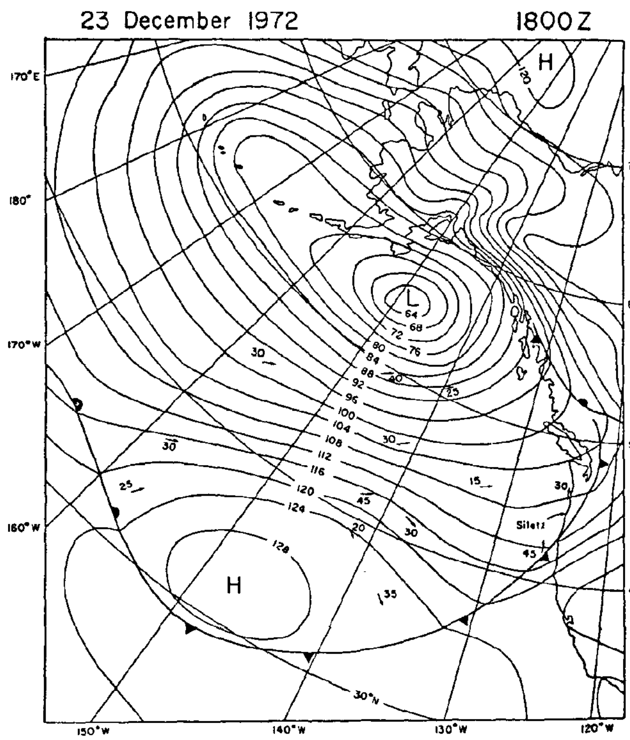


Figure 8. Storm system on December 23, 1972 with winds blowing across most of the Pacific and directed toward Siletz Spit. This storm generated unusually high waves along the Oregon coast which caused major erosion at Siletz Spit and elsewhere.

Waves reach Oregon from storms in the far South Pacific as well, although they are not nearly as large as those generated by storms in the North Pacific. Komar and McKinney (1977) analyzed storms such as that of Figure 8 and their role in generating waves and beach erosion on the Oregon Coast.

Ocean wave conditions have been measured daily at Newport by a seismic recording system that detects microseisms produced by the waves. This yields a measure of the highest one-third of the waves, as well as the periodicity of the wave motions. This system has been in operation since November 1971, measuring waves four times daily. This wave data set is the longest and most complete available for wave conditions on the Oregon coast, and has been summarized by Komar, et al. (1976b) and Creech (1977).

Figure 9 gives an example of the annual changes in wave heights and periods, this example extending from July 1972 through June 1973. The solid lines give the average wave breaker heights and periods for

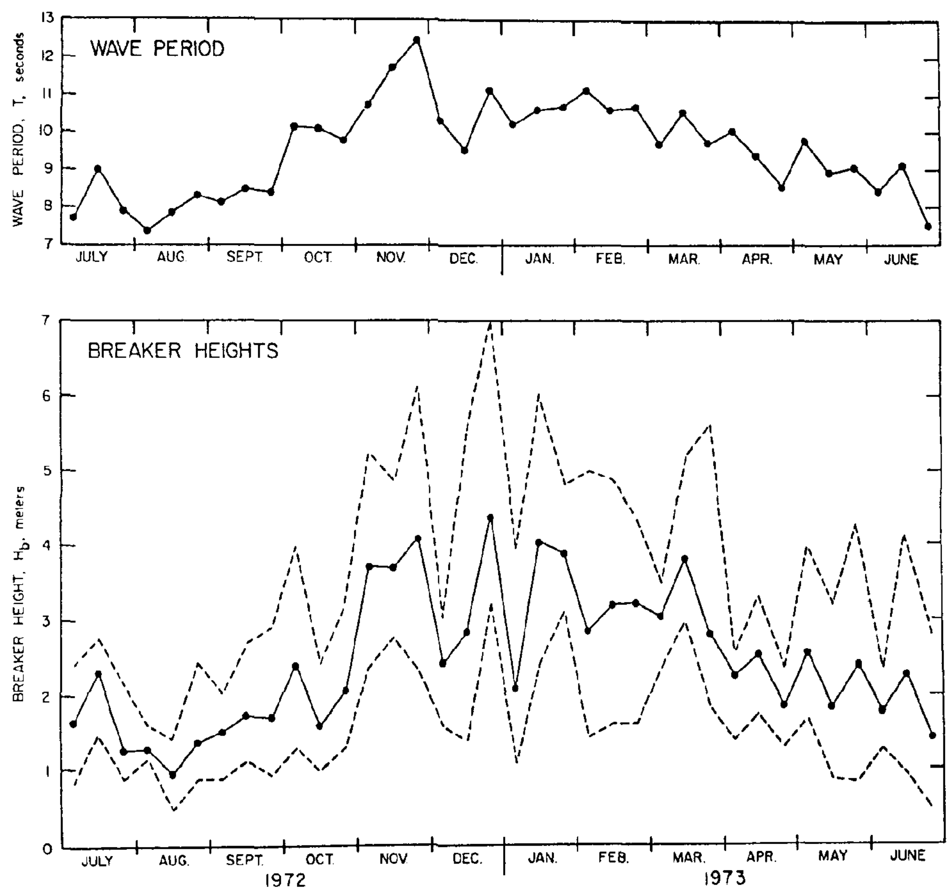


Figure 9. Significant wave breaker heights and periods measured at Newport during July 1972 through June 1973. Each datum point gives the average for one-third month. The dashed lines give the maximum and minimum breaker heights during those one-third month intervals. Note the arrival of large storm waves during the last part of December 1972, caused by the storm of Figure 8.

each one-third month. Also given are the maximum and minimum wave breaker heights that occurred during those one-third month intervals (the dashed lines). It is seen that much larger breaking waves prevail during the winter months, reaching an average of about 15 feet. However, individual storms produce maximum daily waves with significant heights of some 23 feet. Such storm waves occurred in the last one-third of December 1972, (Figure 9), associated with the storm system of Figure 8. Breakers of 23-foot height are truly exceptional. The seismometer system has measured such high waves only three times since its installation in 1971--in December 1972, October 1977 and February 1978. Each instance was marked by severe beach erosion along the coast. Thus, not unexpectedly, unusually high waves are largely responsible for the episodes of coastal erosion.

F. Beach Cycles

Beaches respond to seasonally changing wave conditions as schematically illustrated in Figure 10 and for the beach at Gleneden Beach in Figure 11. During the summer months of low waves, sand moves onshore forming a wide berm--the nearly flat exposed portion of the beach (Figure 10). During the stormy winter months of high waves, sand is eroded from the berm and moves offshore, depositing there in offshore bars. Such seasonal cycles of the beach profiles occur on most beaches, and have been documented by Aguilar and Komar (1978) on two Oregon beaches (Figure 11). Komar (1977) reviews the Oregon beach profiles obtained during 1945-6 by the U.S. Navy using an amphibious DUKW (pronounced "duck"). Only with such an amphibious vehicle have profiles been obtained over the deep outer bars of Oregon beaches.

Although the cycle between the two beach profile types of Figure 10 is approximately seasonal, they are really a response to high storm waves versus low regular swell waves such as occur most commonly during the summer. But if low waves should occur during the winter, sand will move onshore and the berm widen so that the two types of profiles are not always strictly seasonal.

The principal importance of this cycle of beach profiles is that the swell (summer) profile with its berm helps protect the sea cliffs and foredunes from wave attack and erosion. In contrast, the absence of a berm in the storm (winter) profile allows the waves to swash up against the coastal property, producing erosion. This is one of the principal reasons that wave erosion of coastal properties on the Oregon coast is limited mainly to the winter months.

It is seen that an important role of the beach is that it acts as a buffer between the ocean waves and the coastal property, causing the waves to break offshore and dissipate most or all of their energy before reaching the coastal property. With a wide berm the waves are not able to reach the coastal property at all. Removal of sand from the beach by sand mining, as mentioned earlier, will reduce the total volume of beach material and hence the winter waves have less sand to

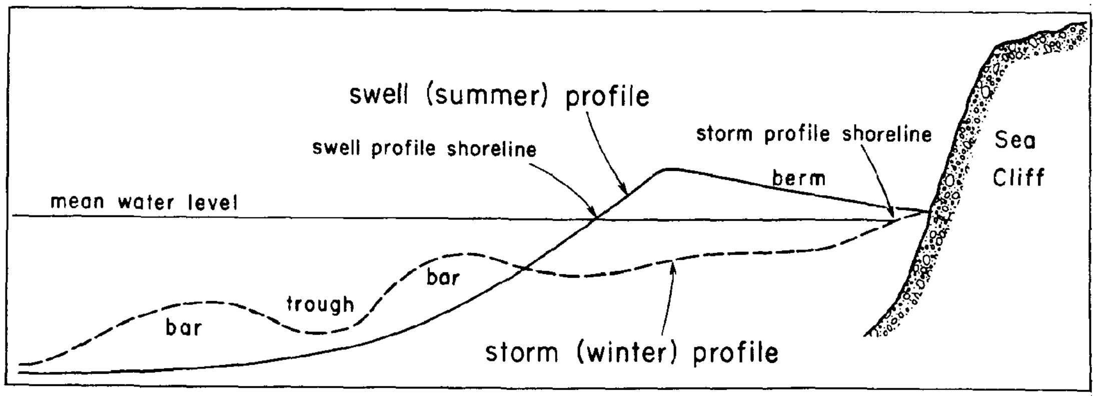


Figure 10. Schematic illustration of the beach profiles produced by storms versus gentle swell waves. On the Oregon coast these profile changes are approximately seasonal due to our storms occurring principally during the winter months.

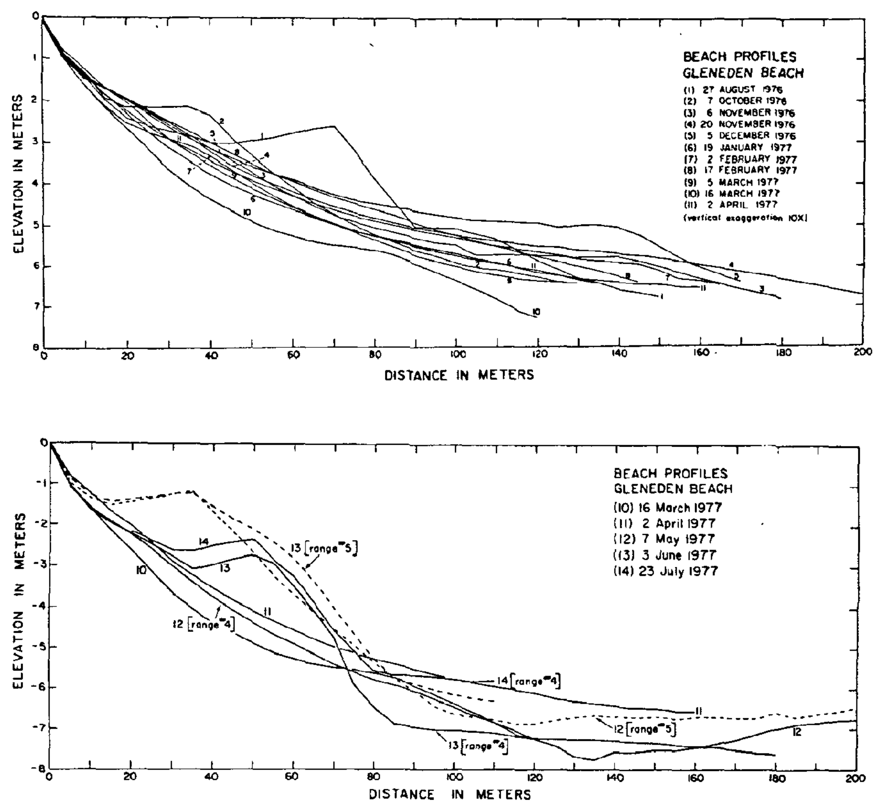


Figure 11. Profile changes measured at Gleneden Beach from August 1976 to July 1977 showing the winter erosion of the exposed portion of the beach followed by deposition as the spring and summer months of lower waves return. The profiles do not extend far enough offshore to show the offshore bars (from Aguilar and Komar, 1978).

shift offshore before attacking coastal property. Sand mining reduces the beach's ability to act as a buffer between the land and the erosive ocean waves.

G. Nearshore Currents and Sand Transport

Waves reaching the coast generate currents in the nearshore zone that are important to sand movements on the beach and to beach erosion. These currents are independent of the normal ocean currents that prevail further offshore, being negligible on the beaches (except for the tidal currents which are important to beach processes in some cases).

When waves break at an angle to the shoreline they generate a current that flows parallel to the shoreline (Komar, 1976, Chapt. 7). This current, together with the waves, produces a transport of sand along the beach known as littoral drift. On Oregon beaches the waves tend to arrive from the southwest during the winter months and from the northwest during the summer (corresponding to the changes in wind directions). As a result, there appears to be a seasonal reversal in the direction of littoral drift; north in the winter, south during the summer. The difference between the two, the net littoral drift, appears to be nearly zero, at least when averaged over a number of years.

That the net littoral drift is essentially zero is demonstrated by the absence of continuous accumulations of sand on one side of jetties or rocky headlands, with erosion on what would be the downdrift side. Instead, sand tends to accumulate and/or erode symmetrically around newly constructed jetties. The major rocky headlands appear to protrude sufficiently far out into the sea that the sands forming the beaches cannot pass around them. Thus, they would also block any net littoral drift if it did exist. Instead, the beaches of Oregon are essentially pocket beaches, isolated from one another by the headlands, with zero net littoral drift prevailing in each pocket. For this reason, when one develops a budget of littoral sand for a particular beach the analysis should include the entire length of the pocket beach between two major headlands (as was done in Figure 5). Only the beach of the Clatsop Plain north of Seaside does not fit into this concept of being a pocket beach, this exception being due to the presence of the Columbia River.

Most of the time the waves approaching the Oregon beaches are nearly parallel to the shoreline trend. Under such circumstances the nearshore currents form a cell circulation, the most prominant part of which are the rip currents (Figure 12), narrow currents flowing offshore away from the beach. The rip currents are fed by longshore currents flowing roughly parallel to shore, but for only a short stretch of beach, unlike the longshore currents which are generated by waves breaking at an angle to the shoreline. The cell circulation pattern illustrated in Figure 12 rearranges the sand on the beach, the feeder longshore currents following troughs in the beach profile shoreward of the offshore bars, and the rip currents bisecting the bars. Of special importance to beach erosion, the rip currents often carry sand offshore, hollowing out embayments into the beach as illustrated in Figure 12. At times these embayments can extend across the entire width of the beach and begin to erode into foredunes or sea cliffs. Such patterns have been important to erosion on Siletz Spit.

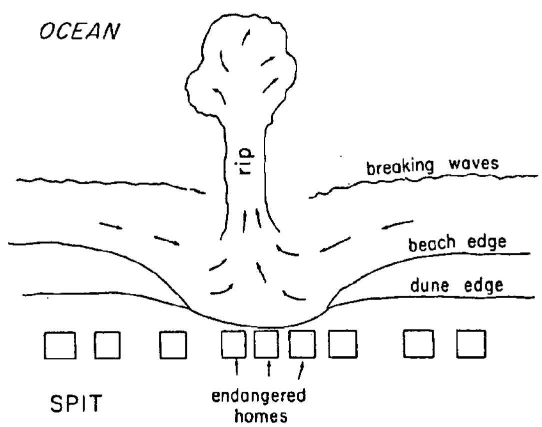


Figure 12. A rip current flowing outward across the beach hollowing out an embayment into the beach and eventually into the foredunes causing property losses.

H. Tides

Tides on the Oregon coast are moderate with a maximum spring tide range of about 13 feet and an average range of about 6 feet. There are two highs and two lows each day, with the two highs and two lows usually of markedly different levels (Figure 13).

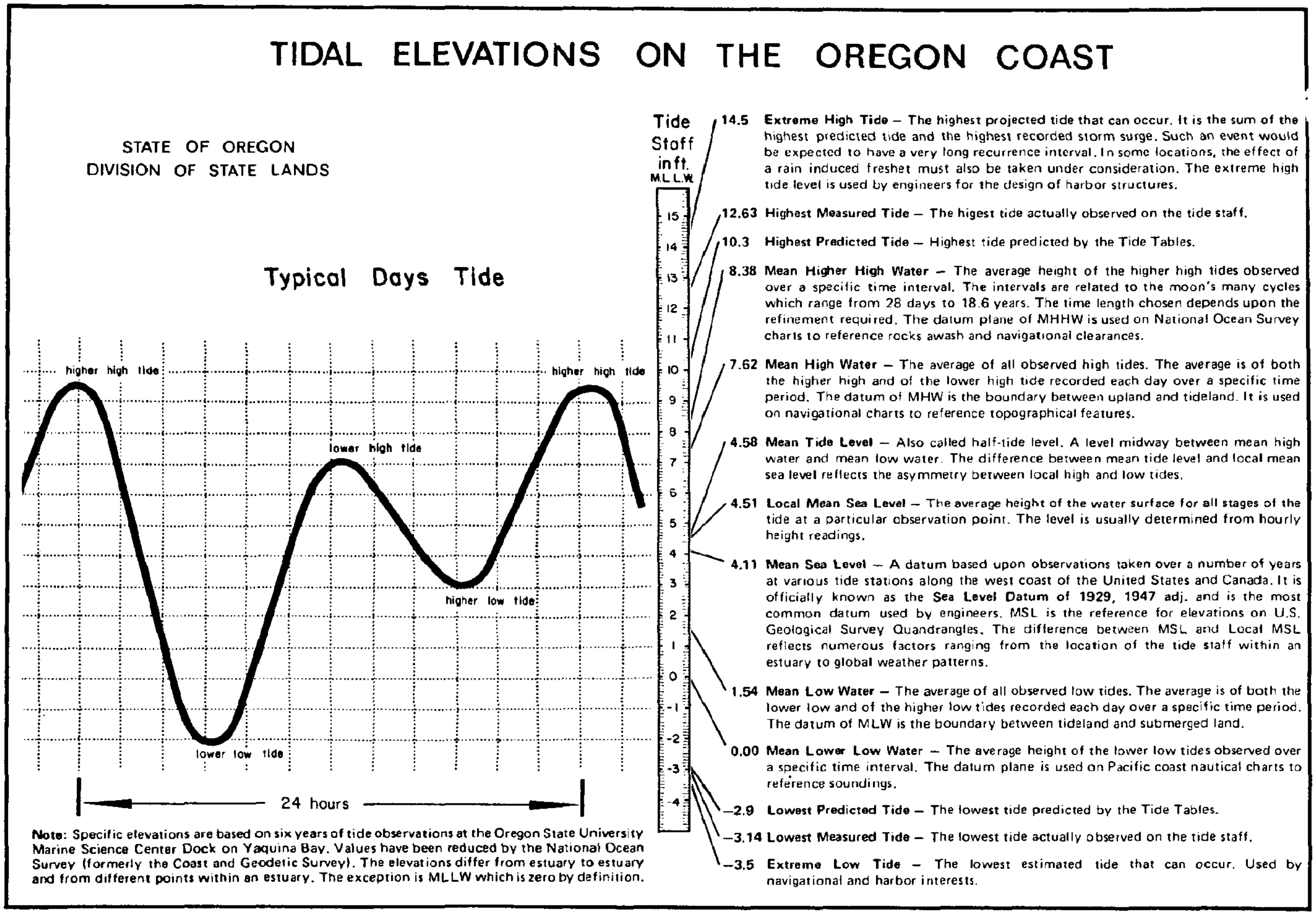


Figure 13. Tidal elevations as measured in Yaquina Bay (from Hamilton, 1973).

Tides are an important factor in coastal erosion in that they govern the hour by hour level of the sea and hence the position of the shoreline and the zone where ocean waves expend their energy. In particular, spring tides may bring water levels high up on sea cliffs and foredunes so that the waves attack the coastal properties directly. Such high spring tides have been shown to aid in the erosion of Siletz Spit and to have had an important part in causing the 1978 breaching of Nestucca Spit. Tides are also significant to the currents which occur in estuaries, especially in the inlets of bays and estuaries.

I. Tsunami

Tsunami are large waves generated on the ocean surface, usually by an earthquake producing a displacement of the sea floor. The most common source of significant tsunami reaching the Oregon coast come from earthquakes in and around Alaska. Two have struck the Oregon coast in recent years--28 March 1964 and 16 May 1968. Their impact on the coast is described in Schatz, et al. (1964), Schatz (1965) and Wilson and Torum (1968).

Figure 14 shows the heights of tsunami waves arriving at various Oregon coast sites during the 1964 episode. It is seen that at each location there is a series of waves, the first wave not always being the largest in the series. In that episode, the maximum wave heights were approximately 10 feet. About the same heights were recorded in the 1968 tsunami.

Maximum destruction from the tsunami occurred along the shorelines of bays and estuaries rather than on the open ocean coastline. This is because at least initially the heights of the tsunami waves increase as they are wedged into the constricting confines of the estuaries. For example, the 1964 tsunami damaged bridges and dwellings along the shores of the Necanicum and Neawanna Rivers (Figure 15), the damage being estimated at $276,000. Other hard hit areas were Cannon Beach ($230,000), the Waldport-Alsea area ($160,000), Florence ($50,000) and Coos Bay ($20,000).

There are few reports of tsunami wave destruction along the ocean shorelines. During the 1964 tsunami four children were drowned as their family slept on the beach at Beverly Beach State Park. This low-lying campground was evacuated twice in 1965 as a result of tsunami warnings (Stembridge, 1975, p. 103). There may be more destruction from future tsunami as many dwellings have been recently constructed in vulnerable areas close to the beach. In addition to low-lying areas that have little or no elevation above the beach, foredune areas can in general also be expected to be vulnerable to tsunami runup. This is because the foredunes commonly have a general oceanward slope that permits the tsunami runup to continue with no direct obstacles. In contrast, areas with sea cliffs should not be endangered as the cliff will reflect most of the energy of the tsunami waves.

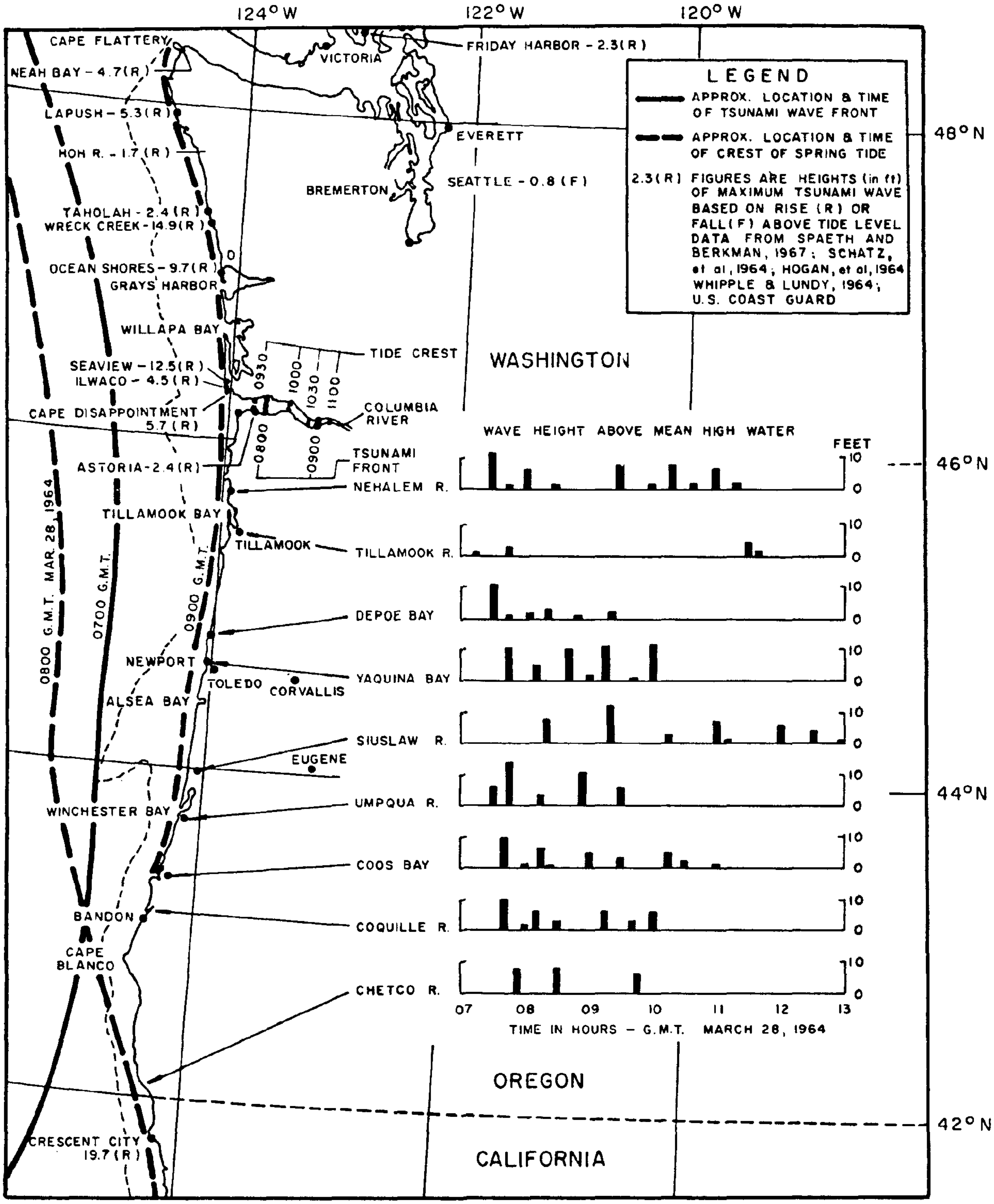


Figure 14. Maximum heights of tsunami waves recorded at tide stations or by observations along the Washington-Oregon coast (from Wilson and Torum, 1968).

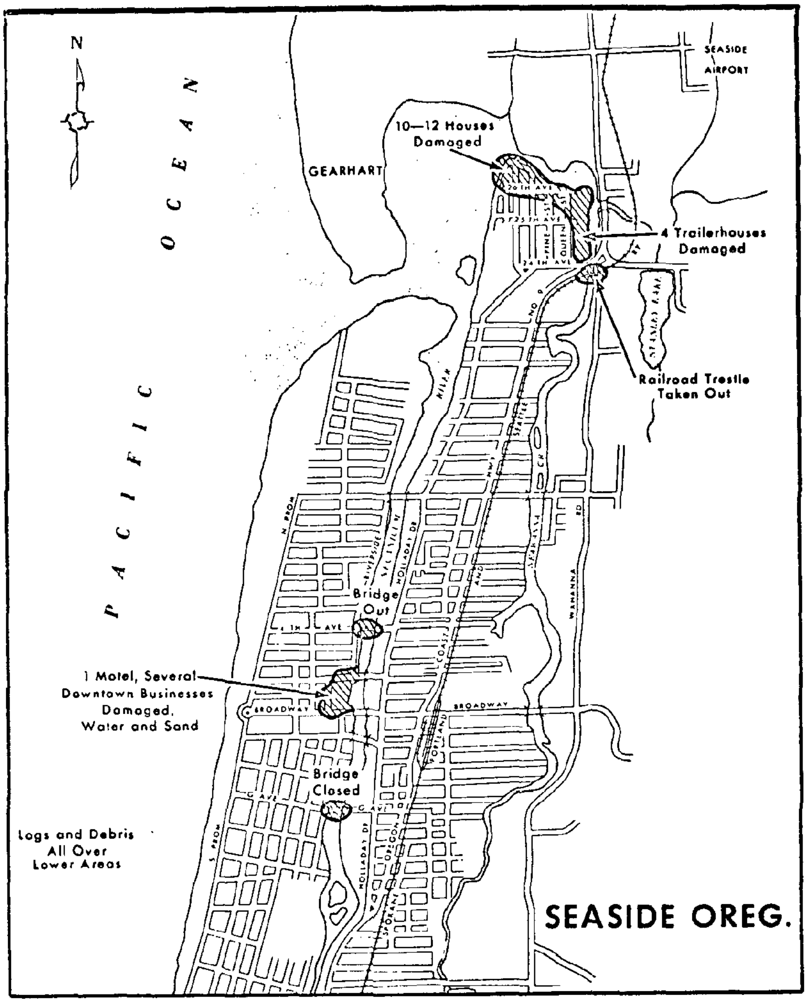


Figure 15. Destruction at Seaside from the March 1964 tsunami (from Wilson and Torum, 1968).

The occurrence of tsunami along the Oregon coast is very sporadic and unpredictable. However, there is a strong probability that another will occur within the next 10 to 20 years. In addition to the estuary areas, almost any foredune or low-lying area can be a potential site for destruction. Unfortunately, with our present understanding of tsunami it is difficult to predict their expected runup for a specific area. Studies following the occurrence of a tsunami show a great deal of variability in the amount of runup along the coastline and the amount of resulting destruction, a variability which at present is poorly understood and cannot be predicted. For this reason, at the present time it is best to be cautious when building on foredunes and in low-lying areas susceptible to tsunami runup.

J. Sea Level Changes

Changes in sea level with respect to the land have important consequences to coastal erosion. With the melting of the Pleistocene ice sheets, which most recently began about 30,000 years ago, water was returned to the oceans causing a rise in sea level. At first this sea level rise was rapid, but about 7,000 years ago it slowed down appreciably (Komar, 1976, p. 154-7). For the past 34 years there appears to be at most a 1.5 mm (0.005 ft.) per year rise in sea level (Hicks, 1972). Hicks determined this rate from long-term tide gauge records obtained on all coasts of the United States. If one averages the recordings of a tide gauge for the entire year, an average water level for that year is obtained. Over the years this level can change, indicating an apparent long-term change in the sea level. The result obtained at a particular coastal site will depend on whether the land there is stable, rising or lowering, as well as on any actual sea level change. For example, on the east coast of the United States the land is sinking so that the apparent sea level rise is still larger than the 1.5 mm/year value (Figure 16). As a consequence, in the long term (tens of years to centuries) the shoreline there tends to migrate landward, resulting in shoreline erosion and endangering dwellings constructed too close to the beach. In contrast, much of Alaska is rising at a geologically rapid rate, much greater than 1.5 mm/year. This results in the land emerging from the sea with the shorelines receeding (Figure 16). If sea level is presently rising at the rate of

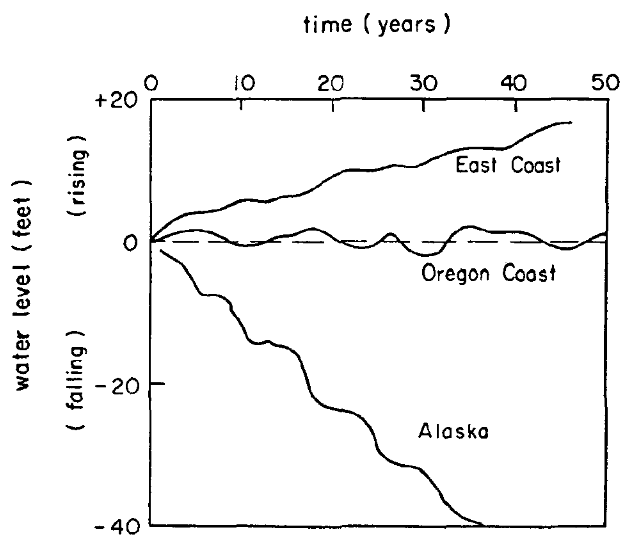


Figure 16. Schematic of water level changes on the Oregon coast as compared to the East coast and the coast of Alaska, based on the data of Hicks (1972).

1.5 mm/year, then the Oregon coast must be rising at about the same rate as the tide-gauge records at Astoria, Crescent City (California), and Friday Harbor (Washington), analyzed by Hicks (1972), all show no apparent sea-level changes over the years (Figure 16). Excepting the yearly fluctuations which have many causes, the long-term trends show a nearly unchanging sea level. In contrast to the east coast, the apparent lack of a rising water level with respect to the land along the Oregon coast should act as a deterrent to coastal erosion. However, as recently as 7,000 years ago the sea was probably transgressing rapidly over the Oregon coastal zone, producing erosion. Insufficient time has passed since then for the coast to come to equilibrium with the present sea level, so that the general erosion of the rocky headlands and terraces is more a response to that past rise in sea level than due to any present-day rise.

III. EROSION DUE TO JETTY CONSTRUCTION

The earliest erosion problems on the Oregon coast were associated with the construction of jetties at the entrances to bays and estuaries. Most of these were installed early in the century, but subsequently have been repaired and in some cases lengthened. Of interest are the causes of the erosion resulting from jetty construction or extension. An examination of these problems also provides information about the littoral drift of sand along Oregon's coastal beaches.

The most dramatic and famous case of erosion due to jetty construction on the Oregon coast is that which occurred on Bayocean Spit opposite Tillamook Bay. Following the installation of a single north jetty, sand accumulated to the north side of that jetty, resulting in sand deposition to the north (Figure 17). At the same time, erosion occurred along most of the length of Bayocean Spit and south past the community of Cape Meares. Somewhat earlier the resort community of Bayocean Park had been developed on the spit; its homes and buildings were progressively undermined by the erosion and lost (Figure 18), so that eventually the entire town disappeared. Erosion to the spit culminated in November 1952 when storm waves combined with high tides to break through the spit at its narrow mid-section, the northern half of the spit becoming an island. The newly breached area became the main inlet to the bay; the former inlet with the jetty began to close. For this reason, in 1956 the U.S. Army Corps of Engineers built a dike across the new inlet, closing it, and the inlet with the jetty opened once again. The story of the development of Bayocean Spit and its subsequent erosion is documented at length in Terich (1973) and in Terich and Komar (1974).

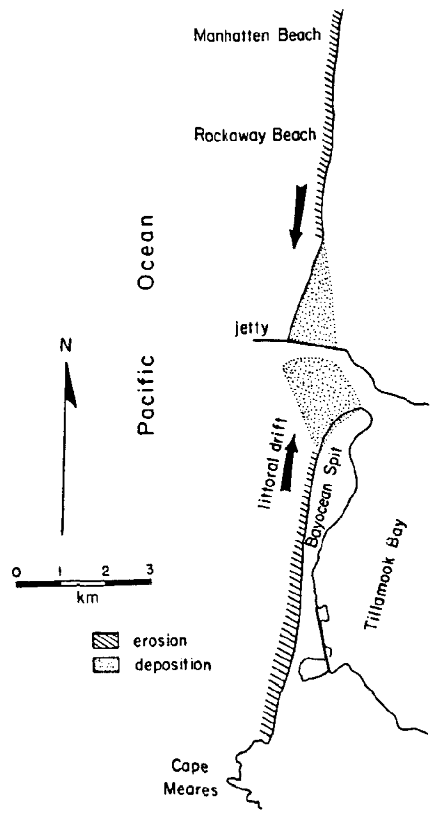


Figure 17. Patterns of beach deposition and erosion resulting from construction of the north jetty at the entrance to Tillamook Bay (from Terich and Komar, 1974).

The sand accumulation to the north of the Tillamook jetty together with erosion along the spit to the south (Figure 17) led early studies to conclude that the jetty construction had blocked a large net littoral drift of sand toward the south. Such patterns of erosion and deposition (beach sand accumulation) are typical of the blockage of a net littoral drift, diagramed schematically in Figure 19A, such as has commonly occurred on the east coast of the United States and in southern California. As previously mentioned it is now believed that this and other beach areas of the Oregon coast have essentially zero net littoral drifts (Figure 19). If a very large net littoral drift did occur in the Bayocean Spit area, then Cape Meares to the south (Figure 17) should have acted similar to a jetty, blocking the drift with a large accumulation of sand on its north side; there is none.

The erosion of Bayocean Spit has to be understood in terms of having occurred under conditions of a zero net littoral drift. Even with a zero net drift there can be local rearrangements of beach sand produced by the jetty construction. Such changes are best seen where two jetties are constructed rather than a single jetty as at the Tillamook Bay entrance.

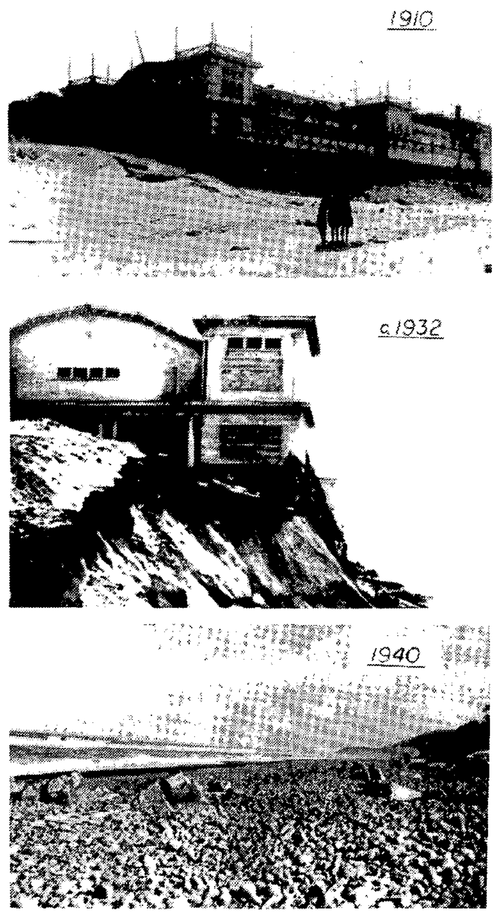


Figure 18. Erosion on Bayocean Spit leading to the loss of the natatorium with an indoor swimming pool (from Terich and Komar, 1974).

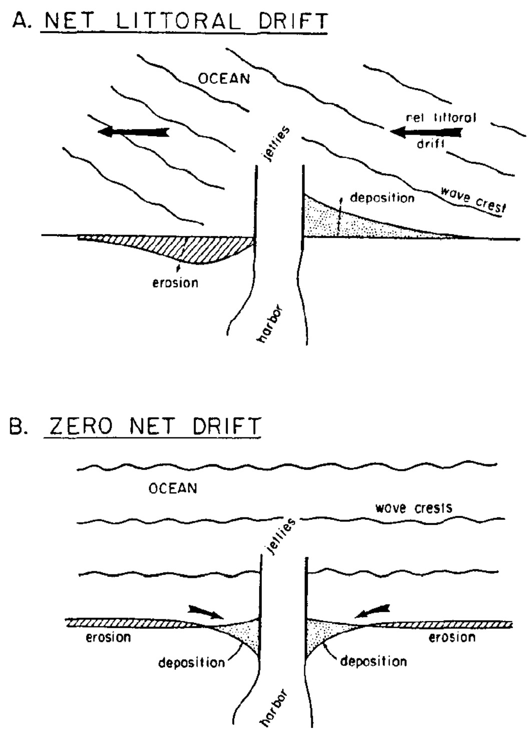


Figure 19. Schematic of shoreline changes (deposition and erosion) produced by jetty construction in areas experiencing a net littoral drift versus an area such as the Oregon coast where there is a zero net littoral drift.

Large shoreline changes also occurred following construction of a pair of jetties at the entrance to the Siuslaw River near Florence (Figure 20). It is seen that where two jetties are constructed, there is beach sand accumulation both to the north and south, immediately adjacent to the jetties. This deposition and shoreline advance occurs because an embayment is formed between the newly constructed jetty and the pre-jetty shoreline. Before jetty construction, the shoreline curved inward toward the inlet and was in equilibrium with both the ocean waves and with the currents coming in and out of the inlet. Jetty construction eliminated the inlet currents acting on that curved portion of shoreline, leaving only the waves. The waves broke at angles to the curved shoreline and so moved sand into the embayment until it completely filled with sand (Figure 21). Once the embayment filled and there was a smooth and nearly straight shoreline parallel to the dominant waves, then a zero net littoral drift once again prevailed. After that stage is reached there are no additional large-scale adjustments of the shoreline due to the presence of the jetties. Therefore a new equilibrium is achieved, and shoreline changes do not continue indefinitely. In the case of the blockage of a net littoral drift (Figure 19A), the only equilibrium that could occur following jetty construction is if the sand accumulated on the updrift side of the jetties until it is able to pass around the jetties to the downdrift side.

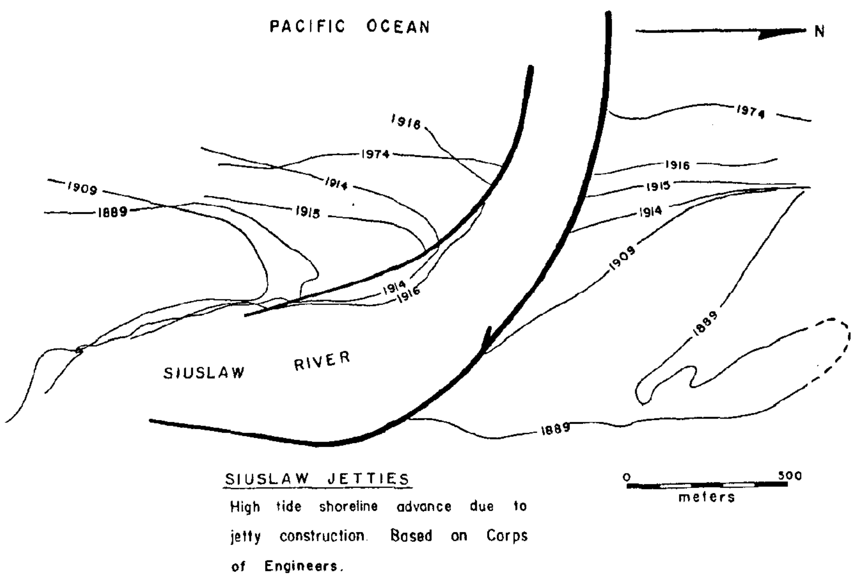


Figure 20. Compilation of shoreline changes resulting from jetty construction at the mouth of the Siuslaw River, based on old ground surveys and aerial photographs. The 1889 shoreline predates jetty construction (from Komar, et al., 1976a).

The sand that fills the shoreline embayments produced by jetty construction must come from somewhere, and most of it comes from shoreline erosion at greater distances from the jetties (Figure 19B). Thus a symmetrical pattern of erosion and deposition results with beach sand accumulation immediately adjacent to the jetties, both to the north and south, and with erosion at greater distances from the jetties (Figure 19B). This contrasts with the asymmetrical pattern where the jetties block a net littoral drift, the shoreline advancing seaward on the updrift side and erosion occurring on the downdrift side (Figure 19A). As in the case for jetty construction on the Siuslaw River (Figure 20), the patterns of erosion and deposition may not be perfectly symmetrical due to the different sizes of embayments created on the two sides of the jetties. In that example the embayment to the north was much larger than that to the south. This required a larger amount of sand to fill the embayment and resulted in greater erosion to the north to supply that sand. Because it is only about 6 miles from the Siuslaw jetties north to Heceta Head, there was a relatively short stretch of beach from which to erode sands to fill the embayment; thus the amount of erosion per unit length of shoreline was large. In contrast, to the south there is a very long length of beach and a smaller embayment to fill; the amount of erosion per unit shoreline was smaller there, nearly negligible. The amount of shoreline retreat produced by jetty construction in areas, such as the Oregon coast where there is a zero net littoral drift, is a function of the size of the embayment to be filled adjacent to the jetty and the length of beach over which erosion occurs to supply the sand.

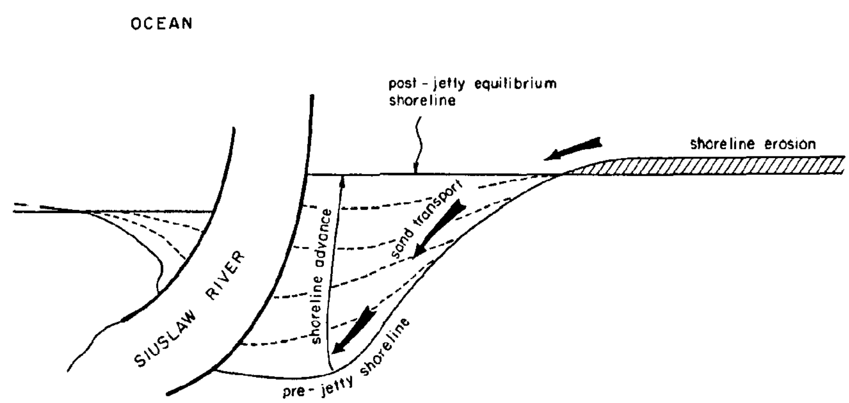


Figure 21. Schematic of the filling of the shoreline embayment created between the newly constructed jetty and the pre-jetty shoreline, the waves causing sand transport into the embayment until it is completely filled and a new straight equilibrium shoreline is achieved.

The coastal erosion associated with the construction of the jetties on the Siuslaw River inlet produced no problems in that the erosion was confined to the early part of the century soon after jetty construction. At that time the coastline to the north was undeveloped so no homes were in the path of the erosion.

The erosion problems at Bayocean Spit were similar, but complicated by the fact that only a single north jetty was constructed rather than a pair of jetties. As at the Siuslaw jetties, there was sand accumulation to the north of the jetty (Figure 17) until the embayment produced by jetty construction was filled and the shoreline straightened. There was probably some erosion further to the north, but the length of beach there is long so that there was only a small amount of erosion per unit shoreline length. Sand also accumulated at the northern tip of Bayocean Spit even though a true embayment was not formed by jetty construction. This accumulation was in the form of a large shoal which developed seaward of the south side of the inlet (Figure 17). That sand apparently came from the erosion of Bayocean Spit, so there was something of a symmetrical pattern of deposition and erosion (Figure 17), similar to that of the Siuslaw jetties. The erosion of Bayocean Spit was large because the eroded sand came from a short length of beach, Cape Meares being to the immediate south. In 1976 a south jetty was constructed at the inlet, forming a true embayment with the pre-jetty shoreline. As at the Siuslaw inlet and other Oregon-coast inlets, the embayment filled until the shoreline was straight with the shoreline along the remaining length of Bayocean Spit. That filling required some additional sand, again derived from further erosion of the spit. However, since that time, erosion of the spit and the Cape Meares area has been small since a new equilibrium exists in which no further sand is required for deposition next to the south jetty.

On the Oregon coast and other areas of zero net littoral drift, once jetties are constructed and sand has filled the embayments to either side, the jetties can subsequently be extended without producing additional major shoreline readjustments and erosion. This is especially true if the jetties are perpendicular to the coastline trend, extending straight out to sea. For example, the jetties on the Siuslaw River inlet (Figure 20) could be extended without causing renewed erosion problems, and the proposed extension of the south jetty at Tillamook Bay will not cause significant additional erosion on Bayocean Spit. However, where jetties are oblique to the shoreline trend, as at the Yaquina Bay entrance (Figure 22), jetty extension produces some additional sheltering from the waves to the enclosed side and results in further sand accumulation next to the jetty and some further erosion at greater distances from the jetty; this was the case with the extension of the Yaquina Bay jetties in 1971.

The filled embayment areas to either side of inlet jetties are dependent upon the presence of the jetties. If the jetties are allowed to degrade then there may be some erosion to these filled areas. A possible example of this may be the recent erosion at Nedonna to the immediate south of the jetties on the Nehalem River. As at the other inlets, following the construction on the Nehalem in 1917, the embayments to either side filled and the shoreline there advanced seaward. No further work has been done on these jetties, however, and they have deteriorated to the point that they are covered with water at high tide. The shoreline again curves back inward into the inlet, but not as much as prior to jetty construction so that further erosion might be expected. The community of Nedonna Beach was developed on the south embayment fill, in an area that was underwater before jetty construction.

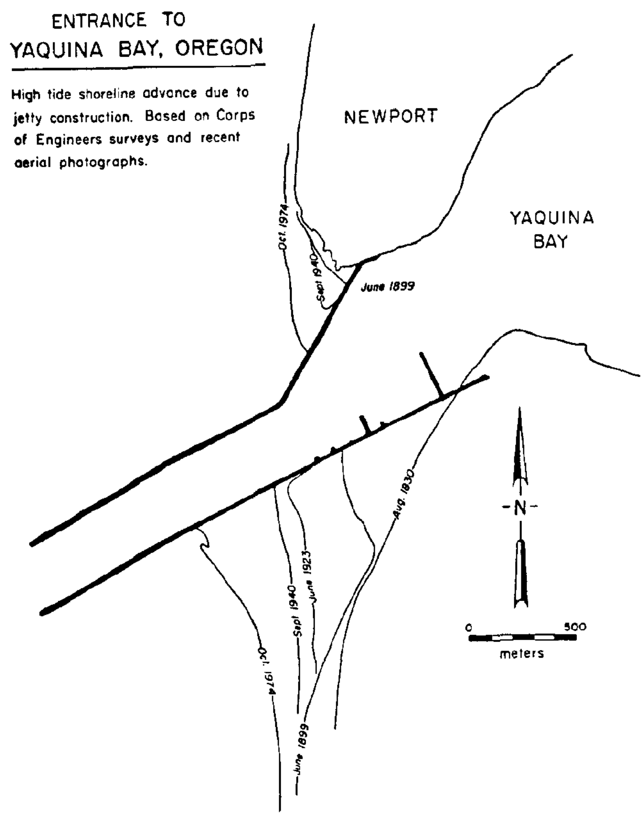


Figure 22. Compilation of shoreline changes resulting from jetty construction and then later extension at Yaquina Bay. The 1830 shoreline predates the jetty construction. The south jetty extension occurred between 1940 and 1974 and is seen to have produced some shoreline advance due to the additional protection caused by the jetty extension (from Komar, et al., 1976a).

All of the jetty systems on the Oregon coast, with the exception of the Columbia River jetties, were studied by Komar, et al. (1976a) to determine patterns of erosion and deposition. All were shown to conform to the pattern of deposition adjacent to the jetties with erosion at greater distances. This provides strong evidence that there is indeed a zero net littoral drift prevailing along the coast of Oregon as discussed earlier.

IV. SAND SPIT AND FOREDUNE EROSION (SILETZ SPIT)

Bayocean Spit eroded due to jetty construction. But other spits, such as Siletz and Nestucca Spits, have also suffered episodes of erosion without the presence of jetties. Their storm wave erosion problems are therefore attributable mainly to natural causes, man playing a minor role in the processes. This section will deal with such natural erosion to the fragile sand spits, especially that which has occurred on Siletz Spit as the problems there have been extensively studied (Rea, 1975; Rea and Komar, 1975; Komar and Rea, 1976b; McKinney, 1977; Komar and McKinney, 1977).

Prior to 1960, Siletz Spit appeared much as it had for hundreds of years; over most of its length there were low hummocky dunes, active or sparsely covered with dune grasses. Development of the spit began in the early 1960's. A road was cut along its length and artificial lagoons were carved into the bay-side of the spit. A scatter of houses appeared.

Following spit development, beach erosion first appeared during January 1971 when a series of storms cut into the foredunes upon which homes had been built. Several homes were in the path of the erosion, but riprap placement halted the erosion advance before they were seriously threatened.

Erosion returned in the winter of 1972-73. A major storm occurred over the North Pacific in late December 1972 (Figure 8), generating wave breakers up to 23 feet in height (Figure 9). The waves cut into the foredunes, quickly threatening several homes. A house still under construction was left unprotected and so was undermined by the retreating dune bluff and collapsed onto the beach (Figure 23). Riprapping began on Christmas Eve to protect the other homes. However, these houses were initially defended only on their seaward sides, empty lots to either side being left unprotected. Foredune erosion and retreat continued in these empty lots, flanking the riprap fronting the homes, necessitating the placement of rocks along their sides as well as fronts (Figure 24). The result was groups of homes situated on promentories extending out onto the beach, supported by riprap on three sides.

Erosion has returned in varying degrees in subsequent winters. It was particularly severe during the winter of 1975-76 and again in 1977-78 when a storm generated breaking waves about 23 feet high, and at a time of high Spring tides. The combination of large waves plus high tides nearly breached the spit (Figure 25). This same storm did breach Nestucca Spit, (see Section V).

In each instance foredune erosion did not occur over the entire length of the spit. Instead, it was limited to two or three zones, each some 200 feet of spit length. This localization of dune erosion was governed by the positions of rip currents as previously discussed (Section II). The seaward flowing rip currents transport sand offshore, hollowing out embayments into the beach berm. At times these embayments reach across the entire beach and begin to cut into the foredunes on Siletz Spit, setting the stage for severe erosion. The major erosion itself occurs during a severe winter storm which produces high wave conditions along the coast. The large waves are able to move ashore over the deep water of the embayments with little loss of energy, swashing directly against the base of the foredunes, cutting them back. Such embayments are seen in Figure 26 at the time of the December 1972 erosion; major foredune erosion occurred shoreward of the most pronounced embayment.

Figure 23. Destruction of house under construction on Siletz Spit due to the rapid wave erosion of the foredunes upon which the house was being built (from Komar and Rea, 1976).

Figure 24. House left on a promentory of riprap on Siletz Spit as adjacent unprotected empty lots continued to erode (Photo by P. D. Komar, 23 January 1973).

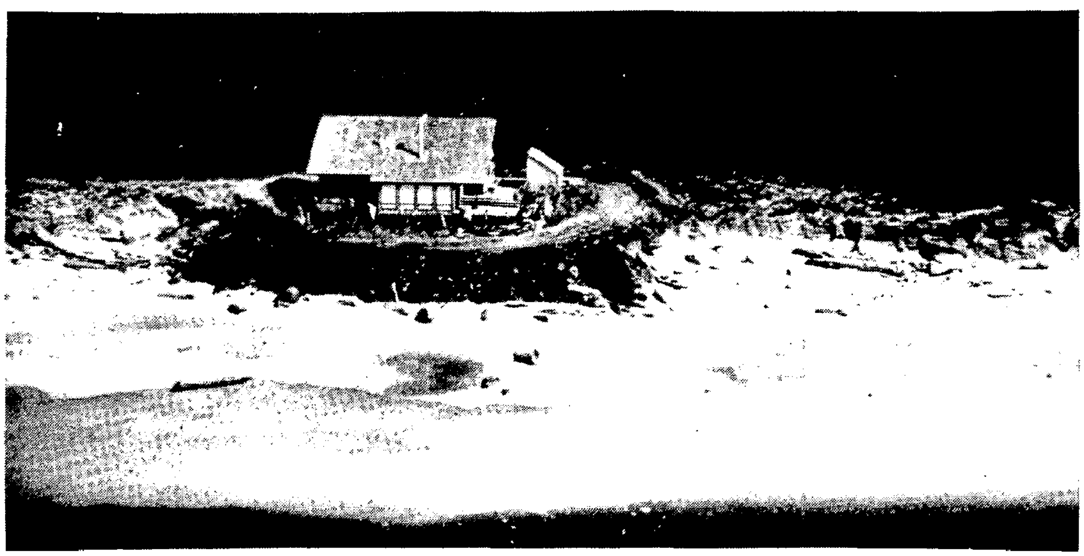


Figure 25. Erosion during the winter of 1977-78 along the narrowest portion of Siletz Spit, nearly leading to its breaching (Photo by P. D. Komar).

Figure 26. Embayments cut out of the beach and into the foredunes on Siletz Spit leading to property losses during December 1972 and January 1973, produced by seaward flowing rip currents (from Komar and Rea, 1976).

Thus the positioning of the rip currents during the winter governs the locations of maximum beach and foredune erosion. This usually changes from one winter to the next so the areas of erosion are not always the same. At present we are unable to predict where the rip currents will form. But once it is seen where they are positioned we can anticipate that these could be potential erosion sites. During some winters they remain relatively fixed in position and so are able to hollow out large embayments; such conditions are most conducive to major erosion. During other winters the rip currents migrate somewhat north-south, probably when waves arrive obliquely to the coastline, and do not form as large embayments; consequently the potential for erosion is smaller.

During severe episodes of erosion on Siletz Spit, the foredunes were cut back some 100 feet around the lengths of ocean-facing lots. Studies of aerial photographs dating as early as 1939 show that such erosion has occurred repeatedly in the past, but that following the erosion, beach sand is washed and blown into the eroded zone eventually rebuilding the foredunes (Rea, 1975; Rea and Komar, 1975; Komar and Rea, 1976b). The following sequence of events is revealed by aerial photographs and is typical of many cycles of erosion and accretion of the foredunes: (1) high storm waves erode an embayment or vertical scarp into the foredunes; (2) subsequent high tides deposit drift logs in the eroded embayment; (3) lower energy waves during the summer build a wide beach; (4) the logs behind the beach trap sand that is either blown off the beach or washed there by the waves at high tides; (5) wind-blown sand continues to accumulate around the logs, sometimes aided by dune grasses, until the foredunes are re-established; (6) erosion again occurs to repeat the cycle. If uninterrupted, one complete cycle can take from ten to fifteen years. Figure 27 illustrates the process of dune reformation (steps 4 and 5) in a small embayment cut into the foredunes. The criss-crossing matrix of logs is seen to be effective in trapping sand to re-establish the foredunes. Drift logs can therefore be an important agent in the reformation of foredunes.

Such cycles of erosion and foredune accretion have occurred repeatedly in the past, shown by the sequence of aerial photos of the Siletz Spit. It is also indicated by the presence of sawed drift logs buried within the foredunes, revealed by the erosion. Many homes built on Siletz Spit were constructed on foredune areas that had previously been eroded away and then reformed as described above--erosion which occurred as recently as the 1950's and early 1960's, just before spit development.

In summary, erosion of foredune areas can be very rapid, removing some 100 feet of property in two or three weeks. The erosion is mainly centered in the lee of rip currents which hollow out embayments into the beach. Maximum erosion occurs under large storm waves, and is also aided by the high water levels of Spring tides. Following erosion the foredunes may be re-established by beach sand washing and blowing into the eroded zone; drift logs aid in dune reformation by trapping the wind-blown sands.

Figure 27. Drift logs washed into an embayment cut by a rip current on Siletz Spit, now actively trapping wind-blown sands and beginning to reform the foredunes (from Rea and Komar, 1975).

It would have been preferable if development on Siletz Spit had been prohibited in the approximately 100 feet zone where foredunes are susceptible to rapid wave undercutting and erosion. Then the natural cycle of erosion followed by dune rebuilding could have continued. Instead, the presence of the homes necessitated the placement of huge quantities of riprap to the detriment of the spit's appearance (Figure 28). Much of this riprap was placed on an emergency basis, without the benefit of correct engineering procedures. As a result this riprap is being progressively washed away (Figure 29) and will have to be replaced at additional cost to the homeowners.

Figure 28. Large piles of riprap employed on Siletz Spit to protect the homes built on the foredunes.

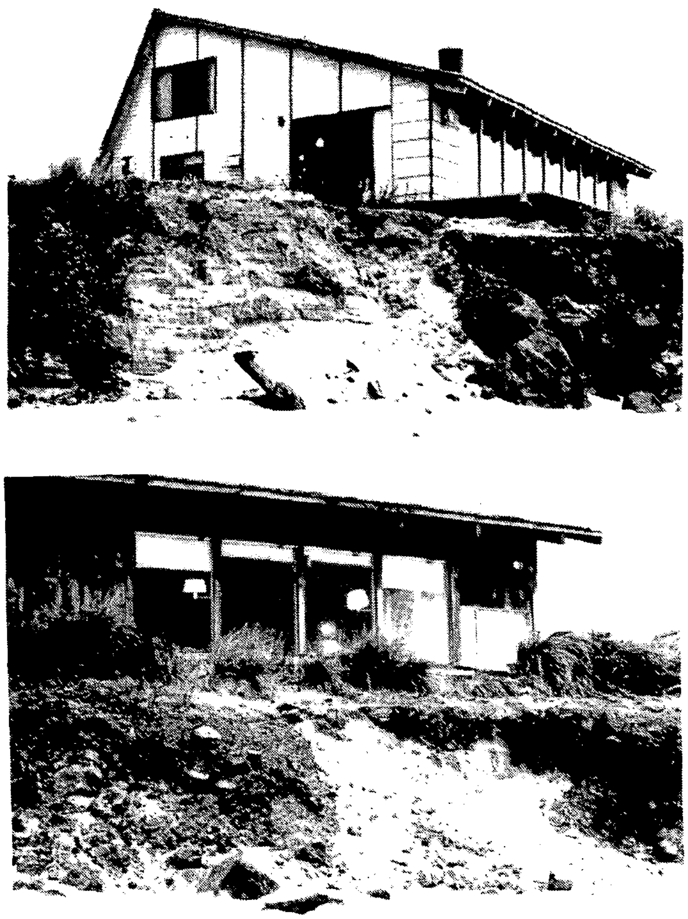


Figure 29. Erosion of riprap on Siletz Spit by a series of storms, exposing the dune sands to wave attack (from Rea and Komar, 1975).

V. OTHER AREAS OF FOREDUNE EROSION OR POTENTIAL EROSION

Other sand spits and foredune areas have suffered erosion on the Oregon coast in addition to that which has occurred on Siletz Spit. Even though erosion may not have been noted in the recent past, all foredune areas have the potential for rapid wave erosion due to their negligible resistance to wave attack. This section will discuss other sand spit and foredune areas that have eroded or have the potential for future erosion.

A. Nestucca Spit Erosion

The erosion of Nestucca Spit, Figure 30, is comparable in extent and in processes to the erosion on Siletz Spit, already discussed (Komar, 1978). The erosion has threatened a number of homes at the Kiwanda Shores development to the south of Cape Kiwanda, necessitating the placement of large quantities of riprap even before house construction was complete (Figure 31). Maximum erosion occurred during the winter of 1977-78; under the onslaught of 23-foot high breakers at a

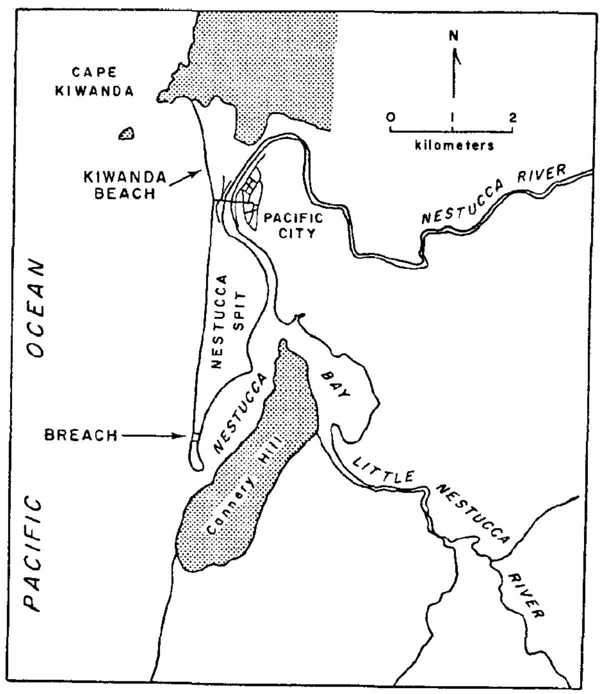


Figure 30. Nestucca Spit, showing the areas of foredune erosion and breaching during February 1978 (from Komar, 1978).

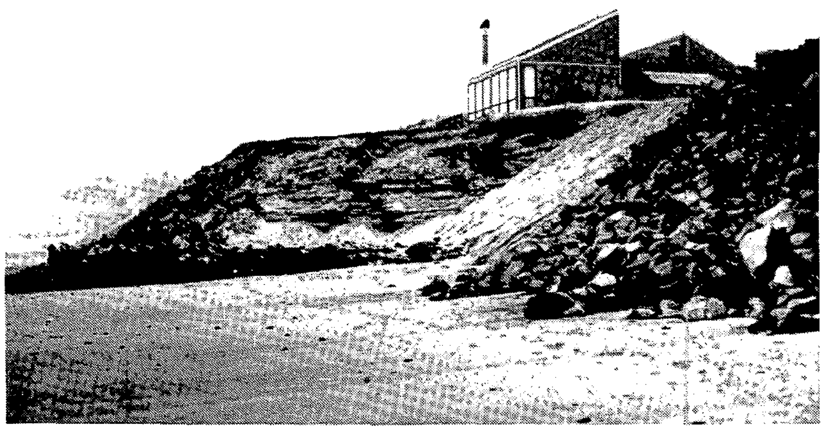


Figure 31. Homes to the south of Cape Kiwanda protected by riprap placed due to the erosion of the foredunes upon which they were being constructed (from Komar, 1978).

time of high Spring tides on 5 February 1978, the resulting erosion broke through the spit near its southern end (Figure 32). This is the only known occurrence of the natural breaching of a sand spit on the west coast of the United States (the breaching of Bayocean Spit, discussed above, was not natural in that the ultimate cause was the construction of jetties). Fortunately, the breached site at Nestucca Spit was well away from any developments and so threatened no dwellings. However, it did demonstrate the fragile nature of sand spits and their general unsuitability for development.

Figure 32. The breach in Nestucca Spit produced by a combination of unusually high storm waves and high Spring tides in early February 1978 (State of Oregon, Highway Department photo).

The erosion processes on Nestucca Spit are very similar to those on Siletz Spit. Rip current embayments again played a role in determining the centers of maximum erosion. However, the beach sand on Nestucca Spit is finer than on Siletz and therefore the beach slope is somewhat less (see Section II). This causes the rip current embayments on Nestucca Spit to be wide and shallower than on Siletz, and they do not cut as far back into the foredunes. The result is that foredune erosion on Nestucca Spit tends to cover a longer length of coastline, but does not reach as far inland. During the time of maximum erosion and breaching, sawed drift logs were observed within the eroding foredune scarp. As at Siletz, this indicates that these foredune areas have eroded before, since logging began in the coastal watersheds about the turn of the century.

B. Netarts Spit

Netarts Spit has a total length of about 5 miles, and is wide to the north but very narrow in its middle section. The spit is covered with dunes, the highest reaching nearly 50 feet high. To the south the dunes are apparently old as they are covered with Sitka spruce. Elsewhere the dunes are vegetated only with low pines or sparse dune grasses.

Erosion of Netarts Spit by wave attack was apparently a threat to the southern portion prior to 1940. Dicken (1961, p. 57) suggests that there is evidence that the spit may have broken through early in the century in its narrow portion. In 1940 the State of Oregon developed Cape Lookout State Park at the spit's southern end. The State constructed a wood piling bulkhead backed by riprap along 600 feet of the park where erosion had apparently been occurring (Figure 33). On the basis of aerial photographs, Stembridge (1975, p. 80) estimates that erosion has amounted to only 10 to 15 feet since 1939.

Figure 33. The wood piling bulkhead built on Netarts Spit to stop wave attack of the dunes.

The dune bluff facing the ocean is vegetated and also testifies to the fact that little or no erosion has occurred in recent years. At times the waves do reach the base of the slope, making a slight notch into the dunes, but this has been minor. It would probably take a very unusual combination of storm waves, high tides and a storm surge to cause appreciable erosion on the spit. At present, the chief problem is due to visitors cutting paths through the dune vegetation (Figure 34) which may lead to wind erosion of the dunes.

Figure 34. Degradation of the dunes on Netarts Spit due to visitors cutting a path from the beach to the state park.

The sand on Netarts Spit is fine and the beach slope very low. As a result, the rip current embayments are extremely broad and shallow, so much so that they do not appear to play any significant role in beach erosion as was the case on Siletz and Nestucca Spits. This may be a major factor in the general lack of erosion problems on Netarts Spit.

C. Nehalem Spit

Nehalem Spit is an area of low dunes that have been conditionally stabilized by European beach grass, there having been a dramatic growth of the grass in the area since 1939 (Stembridge, 1975, Figure 31). On the basis of aerial photographs, Dicken (1961, p. 66) estimated that the spit has eroded 5 to 10 feet over a 21 year period (0.25 to 0.5 feet per year). As discussed earlier (Section III), there was shoreline progradation adjacent to the Nehalem inlet jetties following their construction in 1910-19. But subsequently that area has also been eroding due to the progressive deterioration of the jetties.

The bluff in the Manzanita area cut by this long-term erosion is now nearing many homes (Figure 35) built a number of years ago. The erosion is progressive, rather than periodic and rapid as at Siletz Spit, so these homes are probably not in any immediate danger. Further south, on Nehalem Spit itself, a number of new homes have been recently constructed on the foredunes close to the beach (Figure 36). There are signs of wave erosion of the foredunes in this area so there may be some potential danger to these houses. Sands are also being actively moved by the winds, which may also lead to problems. Unfortunately, no one has made a detailed study of this area.

Figure 35. Long-term progressive erosion in Manzanita, now nearing some of the homes.

Figure 36. Homes built on Nehalem Spit in an area of active foredunes susceptible both to ocean wave attack and wind erosion.

D. Alsea Spit

Alsea Spit may be the one spit on the Oregon coast that is accreting rather than undergoing long-term erosion. This is to be hoped for as the spit is presently undergoing intensive development over its entire area.

Stembridge (1975, p. 115-120) compared aerial photographs of 1939 and 1974 of the area and found that the south tip of the spit has shown maximum accretion, an average of 10 feet per year. The accretion progressively decreases in amount northward along the length of the spit, until at about 1.6 miles north of the inlet it becomes zero with erosion occurring still further to the north. Erosion rates of up to 2 feet per year have been occurring along the bay side of the spit.

This accretion of Alsea Spit may be related to high sediment yields from the Alsea River as suggested by Stembridge (1975, p. 120). Because the accretion is maximum at the south tip of the spit, it may instead have resulted from a southward migration of the inlet itself, such migrations being common for inlets without jetties. If this is the case, then at some future date the inlet migration could reverse and move back to the north. This would cause erosion on the spit, especially at its south tip, so it would be best not to develop that area.

E. Seaside - The Necanicum River Inlet

An example where foredunes have been eroded by inlet migrations is provided by the Necanicum River inlet at the north edge of Seaside. In past decades the position of this inlet has alternately migrated north and south over a distance of about 4,000 feet. In 1948, for example, it moved well to the south to the very edge of the Seaside community, endangering the sewage treatment plant there. It then moved back to the north causing erosion of the foredunes south of Gearhart.

Seaside and the Necanicum inlet area are at the southern portion of the Clatsop Plains and thus have an abundance of sand. Because of this, whenever the Necanicum inlet migrates away from an area, sand rapidly accumulates to form a foredune. At present, such an active foredune is found north of the inlet at the south edge of Gearhart. However, such foredunes adjacent to the inlet are very susceptible to erosion by renewed inlet migration.

In 1967 the inlet migrated to the north and a spit of foredunes began to develop to the south as a continuation of Seaside. A developer quickly placed riprap over that foredune area so the inlet would not migrate back and reclaim the area. The intention was to construct dwellings on the newly accreted area, but the riprap was placed without a permit and so has been under litigation ever since. The inlet has periodically been attempting to migrate back to the south and has been progressively eroding and undermining the riprap at its northern tip. In the meantime, foredunes have accumulated in the area on top of the riprap. In 1978 these active dunes were bulldozed flat, covered with sludge from the sewage treatment plant and seeded with grass.

Due to their natural migrations, such inlet areas without jetties are particularly dangerous to develop. The strong currents in the inlets can undermine the riprap unless done with jetty-scale material. The deep-water of the inlet also allows ocean waves to reach the shoreline with little loss of energy so that inlet areas can also suffer from wave attack. They are also particularly susceptible to overwash by tsunami waves (Section II). In the particular case of the Necanicum inlet, there will be continuing problems with wind-blown sands due to the particular abundance of sand there.

The Necanicum inlet also provides an example of foredunes and bay-shore properties being eroded by currents within the estuary itself. The Neawanna Creek enters the Necanicum estuary on its north side to the east of Gearhart. In the past few years, the flow of the Neawanna has been eroding the bay-side of Gearhart, necessitating the placement of riprap to protect homes there. It strikes the bay side of the foredunes south of Gearhart and is actively eroding them (Figure 37).

Figure 37. Bay-shore erosion at Gearhart, caused by the flow of the Neawanna Creek against the property.

Such bay-side erosion could also pose a threat to any dwellings placed in the area. Bay-side erosion has similarly occurred on Siletz Spit where the flow of the Siletz River impinges on the spit after flowing across the bay (Figure 38). The erosion there has been aggravated by the placement of the Siletz Keys landfill. Prior to the landfill, river flood waters were able to spill into the south part of the bay (open arrows of Figure 38), but after the landfill blocked these channels

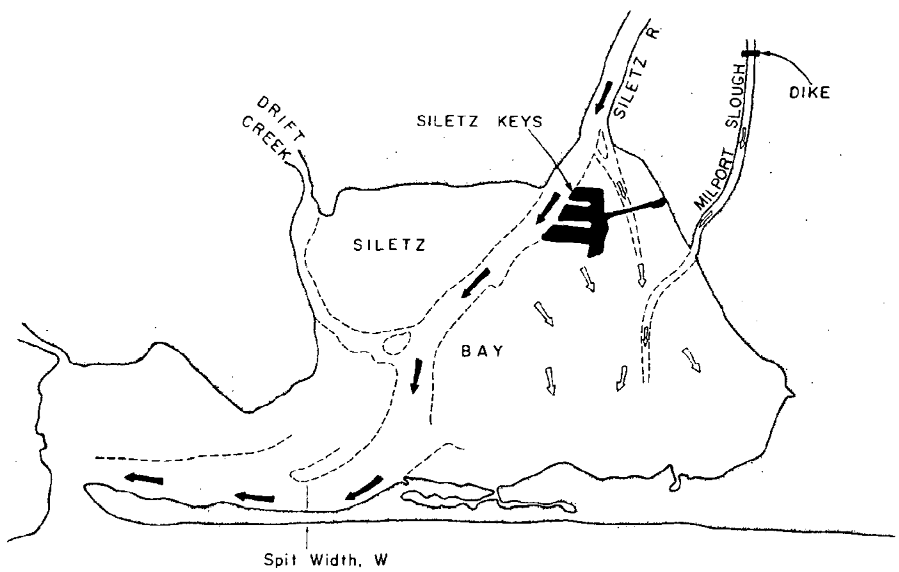


Figure 38. Bay-shore erosion on Siletz Spit where the Siletz River strikes the backside of the spit. The erosion has been aggravated by the placement of landfills such as Siletz Keys which prevents flood-waters from spilling into the south portion of the bay (from Rea and Komar, 1975).

all of the flood waters were jetted against the spit (Rea, 1975; Komar and Rea, 1976b). This bay-side erosion has progressively narrowed the spit, and together with the ocean-side erosion (Section IV), may cause a breaching of the spit (see Figure 25). Old, well-vegetated dunes may also be eroded by bay or estuary currents; an example is the north shore of the Siuslaw River.

F. Cannon Beach (Breakers Point)

Not all foredune areas are located on sand spits are associated with inlets. There are examples where foredunes have formed fronting sea cliffs or older well-vegetated dunes. One example is found in the Cannon Beach area to the north of Elk Creek (Figure 39), a portion of which is presently undergoing development. There are clear signs that the formation of this foredune is quite recent, probably less than 100 years old. At times storm waves cut into the foredunes, much as on Siletz Spit, removing as much as 30 feet during a single storm (Rosenfeld, 1979). This erosion has exposed sawed drift logs, again much as observed on Siletz Spit (Section IV), indicating dune accumulation since logging began in the area. Backing the northern portions of this foredune are higher, older dunes covered with trees. A clear erosion scarp, now covered with grass, has been cut into the seaward-facing side of these older dunes (Figure 39). This indicates that not too long ago erosion proceeded all the way up to the older dunes, entirely removing the foredunes. That erosion must have been an unusual combination of extreme storm waves, high Spring tides and a storm surge, producing an event analogous to the 100 to 200 year flood in a river. Since that event the foredune sands have been accumulating with the exception of the 30 feet or so that is periodically eroded by more common winter storms. Like the river floodplain which is covered by the 100-year flood, this foredune area and others like it are not desirable locations for permanent dwellings.

Figure 39. Foredunes at Breakers Point, Cannon Beach, backed by older, well-vegetated dunes into which waves at some time cut a near-vertical scarp.

VI. SEA CLIFF EROSION

Although not as dramatic as the rapid erosion of foredunes, the long-term, progressive erosion of sedimentary sea cliffs along the Oregon coast remains an important problem for the coastal planner and resident. Certainly on a coast-wide basis, more homes are threatened by sea cliff erosion than by eroding foredunes. This is because many of our coastal communities (Cannon Beach, Lincoln City, Newport, Waldport, Bandon, Brookings, and numerous others) are located in areas of eroding sea cliffs. Most of these are built on the flat areas of marine terraces, consisting of Pleistocene marine sandstones overlying mudstones of older ages. These rocks are susceptible to wave attack to form the familiar sea cliffs (Figure 40) seen along much of the Oregon coast.

This section will examine the processes of sea cliff erosion (including landslides), what is known about their recession rates, and what attempts have been made to protect them from wave attack and the success or lack of success of such attempts. Examples of problems with eroding sea cliffs on the Oregon coast are cited.

A. Processes of Erosion

Erosion of sea cliffs is often viewed as a process of wave attack undermining the cliff followed by landsliding. This view is somewhat oversimplified as other processes are also involved including groundwater sapping and direct erosion by rainwash (especially important in Oregon). The Pleistocene terrace sandstones that form a primary component of the Oregon sea cliffs are only weakly cemented and so are easily eroded away by rainwash and groundwater. The sand so washed away, or that which has dropped from the cliff as a minor landslide, tends to accumulate at the base of the cliff as a tallus pile, sloping toward the sea (Figure 40). Most often the waves are more important in periodically removing this tallus accumulation than in directly attacking the sea cliff itself. The amount of tallus found at the cliff base can give some idea as to the frequency of wave attack in a particular area (Figure 41). A large accumulation, especially one with vegetation growing upon it, indicates that a long period has elapsed since storm waves were able to reach the sea cliffs. This was the case at Taft until the winter of 1977-78 at which time unusually severe winter storms removed the extensive tallus accumulations (Figure 42). A large quantity of drift logs had been removed from the beach fronting Taft, and this too may have played a role in the renewed erosion of the sea cliff.

The absence of any tallus accumulation at the base of the sea cliff indicates a very recent episode of water erosion. Where the fronting beach is narrow, such erosion may occur nearly every winter so only minor tallus accumulations may be found during the summer months. Such areas are generally those that show the maximum rates of overall sea cliff recession. At other areas, Taft being an example, wave attack occurs infrequently and the tallus may accumulate over several years before again being eroded away; such areas generally show smaller rates of cliff recession.

Figure 40. Typical sea cliffs of the Oregon coast formed by erosion of marine terraces. The upper photo shows a thin layer of Pleistocene terrace sands overlying older Tertiary mudstones with an apparent dip to the left. The lower photo, from the Lincoln City area, is a sea cliff composed entirely of terrace sandstones, and is seen to be more susceptible to erosion processes.

Figure 41. The extent of tallus accumulation at the base of the sea cliff can give some indication of the frequency or recency of wave attack. The upper photo from Taft shows a considerable accumulation with the development of vegetation, indicating an extended period of time since wave erosion, in this case the logs possibly offering some protection (compare with Figure 42 of the same area after erosion during the winter of 1977-78). The middle photo from Gleneden Beach shows a sea cliff with a large tallus accumulation but no vegetation, indicating no wave attack for perhaps 5 to 10 years. The lower photo is from the same area, the severe storms of the winter of 1977-78 having washed away all of the tallus accumulation.

Figure 42. Sea cliff erosion at Taft during the winter of 1977-78. Compare with the first photo of Figure 41 of the same area, noting the loss of logs on the beach and the loss of the vegetated tallus slope.

The presence of the tallus slope offers some support to the sea cliff. Once it is removed landsliding usually quickly follows, responding more to this loss of support than from actual wave undercutting of the cliff. In most areas the landsliding consists of only small sections of the cliff dropping down onto the beach (Figure 43). This minor slumping, together with rainwash and groundwater sapping, produces a slow to moderate progressive retreat of the sea cliff and loss of property.

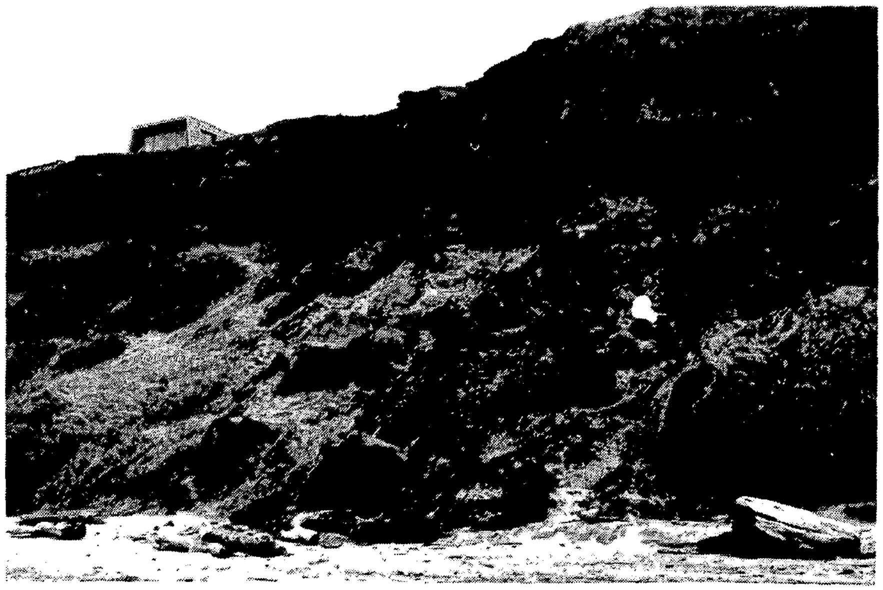


Figure 43. Small landslides are an important process to sea cliff erosion, especially where the cliff is composed of terrace sandstones.

At times, however, large landslides can occur that suddenly remove several acres of land. Important to their generation is the geometry of the sea cliff, including its height and the orientation of the geologic strata forming the cliff. Large landslides are likely to occur in areas where the older rocks underlying the Pleistocene terrace sands slope in the seaward direction as the sliding of the rock mass can occur along this bedding. Byrne (1964) has estimated that such stratigraphically seaward-dipping terrace deposits are present along more than half of the coastline north of Waldport. One such area is Newport where in 1943 an area of about six acres progressively slid seaward, dropping down 20 feet in the process (Figure 44). More than a dozen homes and other structures were lost, some of which originally had been well back from the cliff edge (North and Byrne, 1965; Stembridge, 1975). Figure 45 summarizes the sea cliff retreat over the years in the Newport area, a retreat brought about mainly by landsliding.

Figure 44. Large landslides in the Jumpoff Joe area of Newport.

Another factor important to the generation of large landslides is the presence of groundwater which lubricates the slide, increases the weight of the material, and may also produce a pore-water pressure. Compiling the occurrences of major landslides as reported in coastal

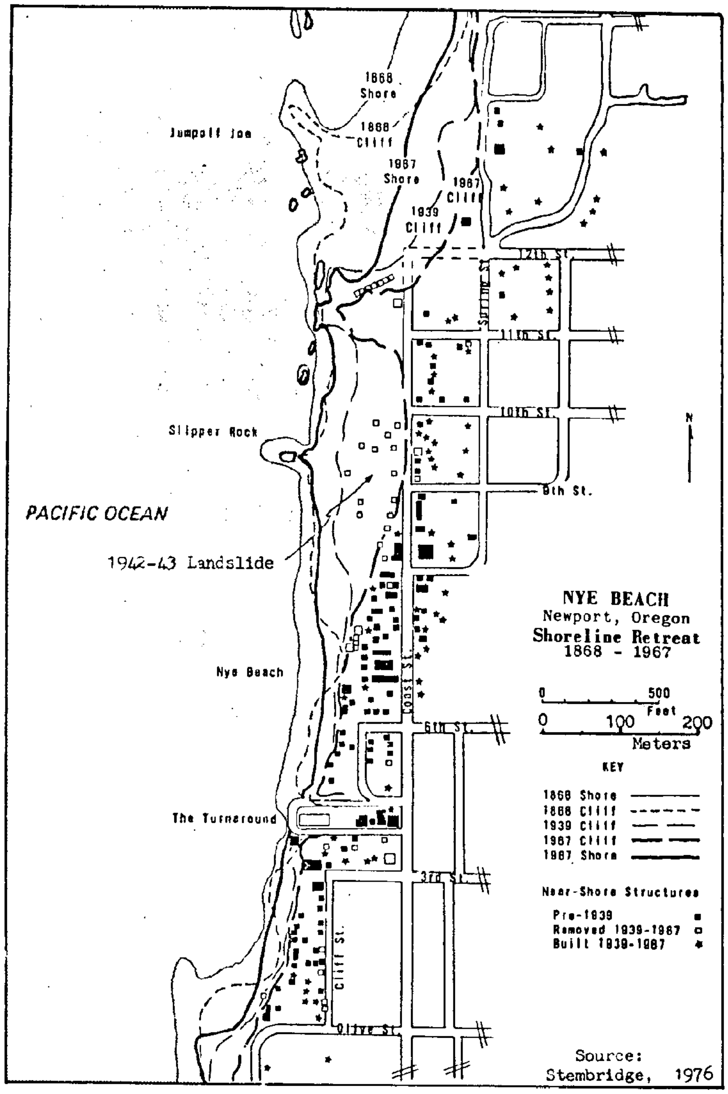


Figure 45. The sea cliff retreat in the Jumpoff Joe area of Newport as documented by Stembridge (1975) from aerial photographs. The property losses here are due almost entirely to large landslides.

newspapers, Byrne (1963) showed that they occur almost exclusively during the months of October through April (Figure 46). Although wave attack may play some role in the winter increase in landsliding, the increased precipitation appears to be more important in that most of the newspaper accounts indicated that sliding occurred during or immediately after extended periods of torrential rains. In more recent years, large landslides appear to have increased in frequency during the summer months rather than being restricted to the winter, probably due to the increased usage of septic tanks which contribute to the ground water at all times of the year.

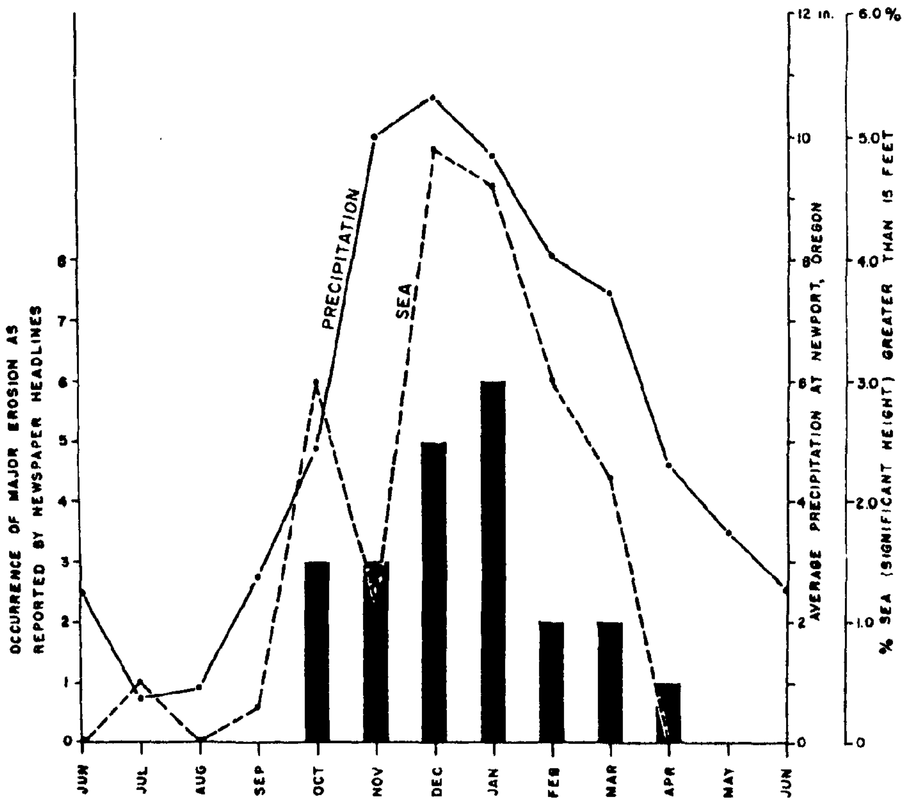


Figure 46. The compilation of landslide occurrences on the Oregon coast from newspaper reports, showing their development during the winter months at times of high precipitation and wave action (from Byrne, 1963).

Large landslides are also important in the headland areas due to the high slopes. The landslides occurring in Ecola State Park are good examples (Schlicker, et al., 1961). Large landslides are particularly common on the flanks of the headlands due to the combination of steep slopes and the presence of loose rock and soil derived from the headland. These areas pose a special problem in that they are often prime sites for housing developments.

Landslides on the Oregon coast have received considerable attention. Byrne (1963), North (1964) and North and Byrne (1965) document landsliding on the northern coast from Florence to the Columbia River. The various reports of the Oregon Department of Geology and Mineral Industries, discuss the hazards from coastal landsliding (for example, Schlicker, et al., 1973). Schlicker (1956) reviews landsliding in general, and Prestedge (1977) discusses the mechanics of landsliding with specific reference to the Oregon coast and the engineering techniques of stabilization.

One additional factor is important to sea cliff erosion--the human factor. Figure 47 illustrates how people can have an impact on the erosion rate by carving graffiti and in some cases even cutting tunnels into the sea cliffs. Considering that natural sea cliff recession rates often amount to only a few inches per year, this human factor cannot be viewed as negligible.

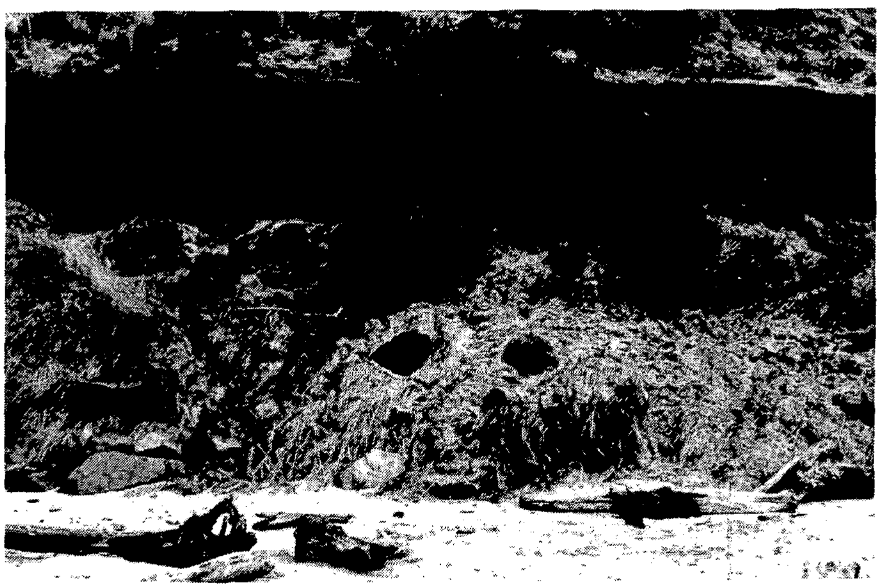


Figure 47. Graffitti carved into a sea cliff at Lincoln City, having a significant effect on the long-term cliff retreat rate.

B. Rates of Sea Cliff Erosion

Of relevance to planning is the long-term recession rate of sea cliffs and the potential for landslides removing large blocks of property in a short time. Landslides have already been discussed, and in most cases their presence or potential is reasonably clear. The progressive recession of sea cliffs is important for determining what distances homes or other structures should be set back from the eroding sea cliff so that they are not destroyed before their anticipated life time of use.

A standard procedure for determining long-term cliff recession rates is through the use of sequences of aerial photographs. There are many difficulties and inherent uncertainties in this procedure so that the amount of erosion measured has to be large if the measured rates are to exceed the uncertainties. This means that the procedure gives best results in areas that have high rates of cliff recession or if there is a very long period of time represented by the available aerial photographs so that even though the rate may be small the total amount of erosion over that period of time is large enough to measure.

The earliest aerial photogaph coverage of substantial stretches of the Oregon coast dates back to 1939. The areas covered by those 1939 photos are diagramed by Stembridge (1975, p. 193). Coverage in the 1940's is scarce, but in the 1950's to the present many more flights were carried out. This forty years of coverage is adequate so long as the cliff recession rates are moderate to high, but if low (less than 2 to 4 inches per year) then the total amount of erosion that has occurred can barely be measured with any certainty by aerial photo techniques.

Stembridge (1975) gives a coast-long summary of the cliff recession rates, based upon the 1939 and 1967 aerial photos and upon field inspections. Table 2 summarizes his estimated erosion rates for backshores of various compositions. The terrace deposits are seen to have a wide range of recession rates, from less than 1 foot per year to greater than 20 feet per year. The large recession rates are found in areas susceptible to landsliding, such as the Jumpoff Joe area of Newport, already discussed. The largest recession rates are for areas of recent sand deposits, the rapid erosion of Bayocean Spit being the primary example (see Section III). Stembridge (1975) does discuss the erosion rates he found for a number of areas along the Oregon coast, as well as presenting the overall summary of Table 2.

Smith (1978) has determined coastal changes for Lincoln County, again using aerial photographs (1939, 1959 and 1973). Erosion rates for that 34-year period range from amounts too low to measure to a maximum of about 240 feet in the Jumpoff Joe area of Newport. The mean amount of erosion was about 20 feet, giving a mean rate of 7.1 inches per year for that 34-year period. Included in that average are some basalt headlands with very low rates of erosion. Excluding those areas from the county-wide average leaves an average of 9.2 inches per year, an average for the coast consisting of sedimentary terraces or unconsolidated materials (the sand spits). Smith found a great deal of variability in recession rates along the Lincoln County coast, so that these averages should not be applied to estimate the recession rate of sea cliffs in some particular area. It would be wise for each county to conduct a study similar to that of Smith (1975) in Lincoln County.

Table 2. Ranges of maximum backshore erosion rates (after Stembridge, 1975)

Backshore Composition	Range of Maximum Erosion (in feet per year)			Examples
Igneous (basalt)	<0.1	to	>0.3	Cape Foulweather, Heceta Head
Metamorphic	<0.1	to	>1.0	
Sedimentary	<0.5	to	>2.0	Cape Kiwanda, Cape Arago
Terrace Deposits	<1.0	to	>20.0	Lincoln City, Jumpoff Joe
Recent Sand Deposits	<10.0	to	>100.0	Bayocean Spit

C. Methods of Sea Cliff Protection

Several methods have been employed on the Oregon coast in attempt to prevent or slow the erosion of sea cliffs. Those most commonly used are riprap and a variety of sea walls. The sea walls may be constructed of concrete or logs; drift logs taken from the adjacent beach are sometimes employed. Groins that project out across the beach to trap part of the littoral sand drift have not been used on Oregon beaches, and probably would not be effective due to the lack of a littoral drift.

All of the protective devices must act to defend the sea cliff from wave attack. In many cases this defense is against only the wave swash rather than the full force of breaking waves. In such cases, a low wall of logs fixed in place at the base of the sea cliff or just in front of the tallus slope is adequate. Great masses of riprap are really needed only where there is severe and direct wave attack. The weight of the riprap does have the added advantage of helping to prevent landsliding as it weights the toe of the cliff. Solid concrete walls have the same effect, but have the disadvantage that they can reflect the wave energy which induces erosion of the beach adjacent to them. This can lead to the undermining of the sea wall and its failure and collapse onto the beach. Log walls and riprap may be partially destroyed by wave attack, but seldom completely fail like a concrete wall.

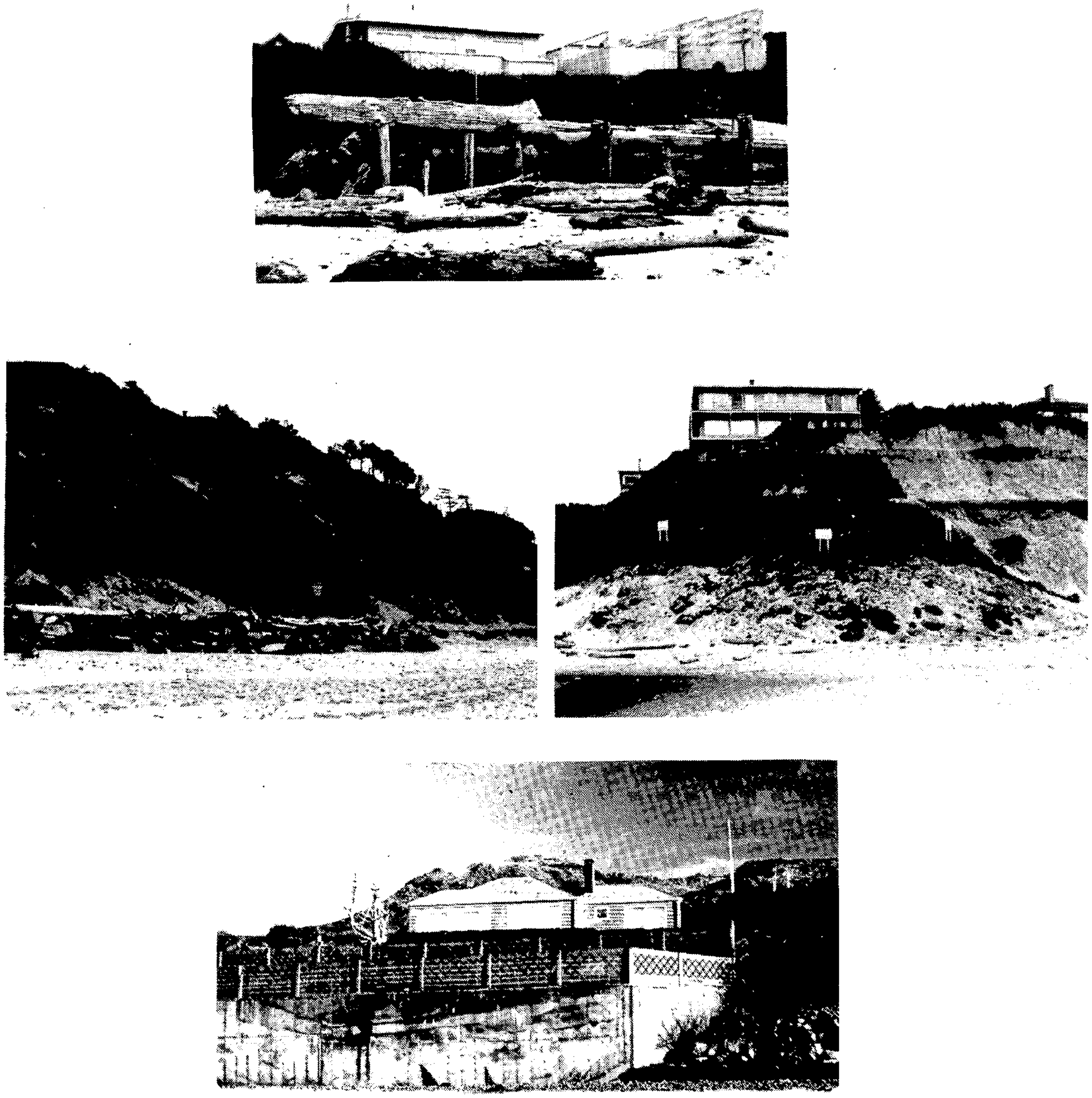


Figure 48. A variety of sea cliff protection approaches have been employed on the Oregon coast, mainly involving log sea walls, concrete sea walls and riprap.

None of these protective schemes completely halt the sea cliff recession unless they extend to the full height of the cliff. If they cover only the base of the cliff, the bare upper portion will continue to suffer some erosion by rain wash and groundwater sapping. This retreat of the top of the cliff will continue until the overall slope of the cliff is decreased, at which time it may become vegetated. But before that stage is reached, the top of the cliff could retreat by several feet, but at a lower rate than before protection was provided to the lower portion of the cliff.

There are arguments against any form of sea cliff protection. First, they can be expensive and would be unnecessary if dwellings were set back an adequate distance from the cliff edge. As discussed in Section II, the erosion of sea cliffs in most cases provides the principal source of sand to the Oregon beaches; cutting off this source by extensive protection will lead to the long-term diminishment of our beaches. And finally, the huge piles of riprap or concrete sea walls can be unsightly, destroying the aesthetic value of the coast that originally attracted people there.

VII. THE COASTAL DUNE SHEETS

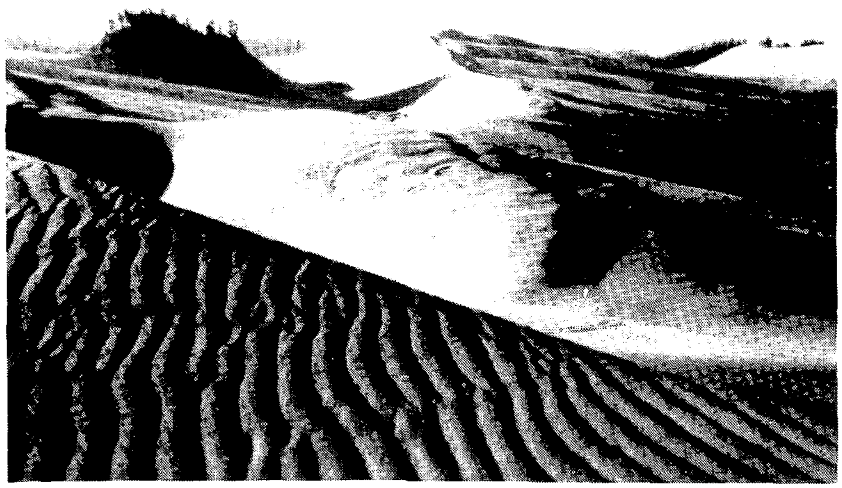
Sections IV and V of this report dealt largely with foredune erosion, whether the foredunes are located on sand spits such as Siletz and Nestucca, or fronting sea cliffs and older dunes as at Cannon Beach (Breakers Point). This section will concentrate instead on the older dunes generally found more inland. It was pointed out in Section II that such dunes, active or vegetated, cover about 45 percent of Oregon's 310 miles of coastline. The best known and most intensely studied is the sheet of active dunes extending for a distance of 55 miles between Coos Bay on the south to Heceta Head near Florence. These dunes and others on the Oregon and Washington coasts were investigated by Cooper (1958), and most of our information on Oregon dunes comes from that source. Later contributions have been made especially by Lund (1973) and various chapters in Dicken (1961). This section will summarize what is known about the physical processes important to dune sand movements on the Oregon coast, the effects of vegetation, and the problems relevant to the management of these areas.

A. Active Dune Types

In his study of the active dunes of the Oregon coast, Cooper (1958) identified two principal types, the transverse-ridge pattern and oblique-ridge pattern (Figure 49). These dune types are somewhat different from those commonly found in deserts and other coastal dune areas.

The transverse-ridge pattern of dunes originally occurred in nearly all the major dune localities on the Oregon coast, but since the introduction of European beachgrass its form has been restricted to the Coos

Bay dune sheet. They are asymmetric in cross-section with windward slopes of 3 to 12 degrees and lee slip faces averaging about 33 degrees, the steepest possible slope for sliding sand. They vary greatly in length; a single ridge may be more than half a mile long. They are not uniform in height, the ridge crest forming a succession of highs and lows.



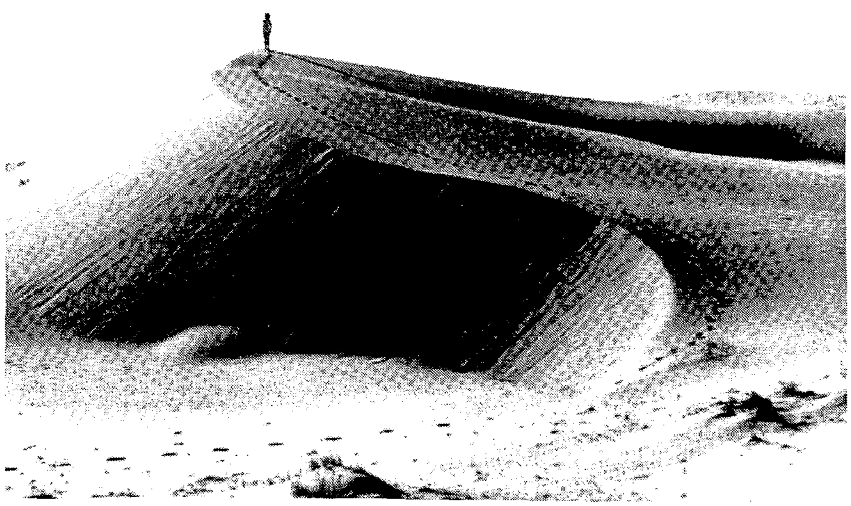


Figure 49. The two active dune types found on the Oregon coast, the transverse-ridge pattern and the oblique-ridge pattern, both now largely confined to the Coos Bay dune sheet. (Lower photo courtesy of Oregon Department of Transportation.)

Cooper has shown (1958, p. 31-33) that the Oregon transverse-ridge dunes are not precisely perpendicular to the controlling northwest summer winds, although they are nearly so. Instead, he found that the transverse-ridges form angles of 11 to 23 degrees to what should be the perpendicular to the wind, facing more to the landward (Figure 50). Presumably the dunes also migrate by this same 11-23 degrees to the left of the wind direction, although Cooper did not demonstrate this to be the case.

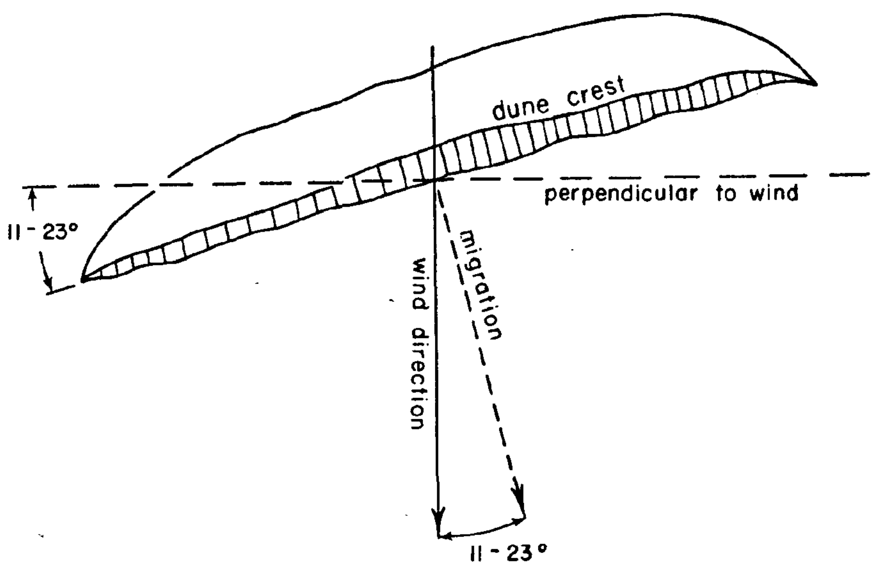


Figure 50. Cooper (1958) has shown that the transverse-ridge dunes do not align exactly perpendicular to the wind direction, instead forming an angle of about 11 to 23 degrees, the dune facing (and migrating) more landward.

Transverse-ridge dunes occupy a strip adjoining the beach or separated from it by foredunes parallel to the shore. Prior to the introduction of European beachgrass and the formation of grass-covered foredunes backing the beaches, transverse-ridge dunes covered the entire area from the beach to the seaward edge of the field of oblique-ridge dunes. Since the introduction of European beachgrass their area has been greatly reduced and continues to shrink. On their inland edge they merge with the field of larger oblique-ridge dunes, the transverse-ridges sometimes climbing up and over the seaward ends of the oblique-ridges. They tend to be smallest near the shore and largest at their inland edge. Average crest to crest distances in fields of transverse-ridge dunes range from 60 to 160 feet.

Cooper (1958) made a few measurements of migration rates of transverse-ridge dunes on the Coos Bay sheet. Measurements were obtained for four dunes with slipfaces over a period of six years. The average rate of advance was 5.2 feet per year, varying from 2.3 to 9.2 feet per year. As expected, most of this advance takes place during the dry summer months of April through August. Also for this reason, the migrations tend to be toward the south to southeast under the north to northwest winds prevailing during those months. Cooper also found that the closer the dunes are to the shore the higher their rates of advance, resulting from the greater wind speeds closer to shore than further inland. He found no correlation between dune height and its rate of advance.

A knowledge of dune migration rates is important in planning measures of dune control or in keeping structures out of the path of an advancing dune. As pointed out by Cooper, his few measurements over a period of six years have to be viewed as the maximum for long-term over-all advance as there may be periods of temporary stabilization with no advancement. Additional study needs to be made of migration rates of these transverse-ridge dunes on the Oregon coast.

The oblique-ridge pattern of dune formation identified by Cooper (1958) occurs only on the Coos Bay dune sheet. They are much larger than the transverse-ridge pattern, forming a series of ridges 4,000 to 5,500 feet in length, aligned with their lengths roughly in an east-west (onshore-offshore) direction (Figure 49). They are highest at a point somewhat shoreward of their landward ends, both in absolute altitude and in height above the immediate base. Cooper measured an average height of 185 feet for ten major dunes. The ridges are spaced rather evenly, particularly at their seaward parts, where the average inter-crest distance ranges between 500 to 650 feet.

On their landward ends the oblique-ridges blend with a ridge of sand that connects them together, the resulting pattern being described by Cooper as a rake, the oblique-ridges forming the teeth of the rake. The connecting ridge is part of the precipitation ridge that has a landward-facing slipface, slowly moving inland and progressively burying the forests that usually lie in the path (Figure 51). This inland advance always appears to be slow (Cooper gives no measurements, however), tending to be somewhat more rapid where the ridge is low.

The oblique-ridge dunes are oriented such that their crests are oblique to both the summer north-northwest winds and to the southwest winds of winter. Most important, they do not migrate, but instead remain fixed in position except for minor shifts with no consistent trend. In cross section the steepest side is usually on the north. During the summer the eroding northern slope is smooth-faced and the south side has a prominant slipface below which is a gentler slope leading to the floor of the adjacent corridor. In most places the windward slope is almost as steep as the slipface. During the summer the oblique-ridge behaves much as a giant transverse-ridge and sand is moved to the southeast. During the winter a slipface of sorts forms on the north side, which is subject to frequent mass slumping, so that even during the winter there is a northward sand transport in the midst of the rain.

Figure 51. A precipitation ridge of the Coos Bay dune sheet migrating slowly landward, burying trees in its path. (Photo courtesy of Oregon Department of Geology and Mineral Industries.)

B. Vegetation Effects

The native flora of the Oregon coast did not provide species capable of building substantial foredunes. Thus prior to the 1940's extensive active dune fields existed, sands blowing inland from the beaches to provide a plentiful supply of sand. In about 1910 European beachgrass (Ammophilia arenaria (L.)) was first brought into the Coos Bay region. European beachgrass took a firm hold and has subsequently spread along the coast producing in many places a prominant foredune where none existed before. These developing foredunes have largely cut off the sand supply from the inland dunes.

The most noticeable effect has been the shrinking of areas covered by transverse-ridge dunes. With the sand supply cut off, the winds erode the dune sands down to the summer groundwater level so that vegetation can quickly take hold. Areas formerly covered by active transverse-ridge dunes have been converted into deflation plains since the 1940's. Comparisons of aerial photos of that period with more recent photos reveal dramatic changes (Figure 52). In places, the areas of open active sand have narrowed by nearly half in 30 years (Lund, 1973).

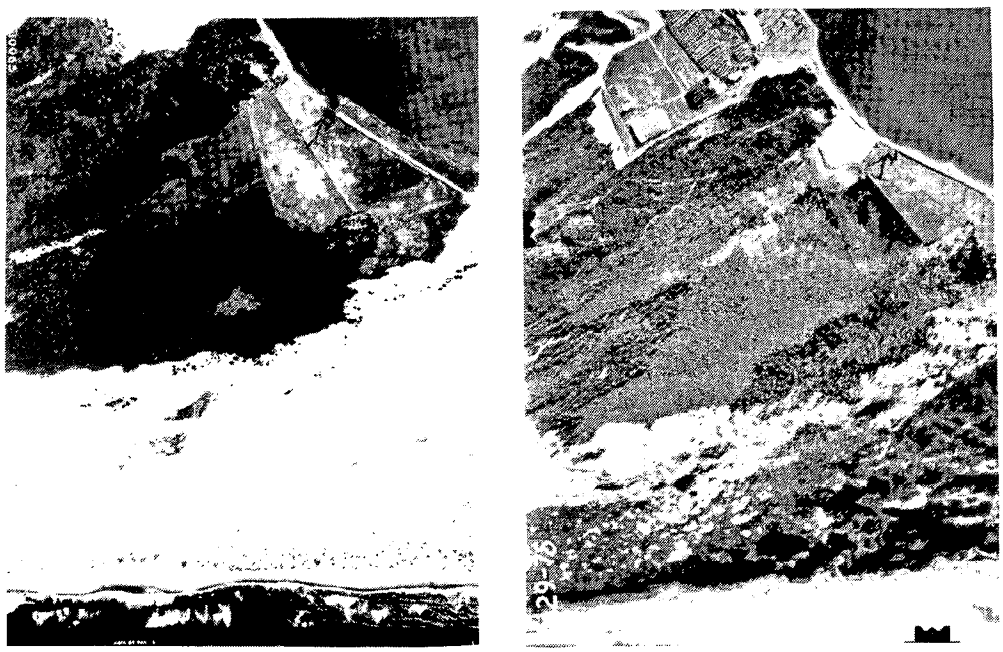


Figure 52. An example of the effects of the introduction of European beachgrass to the Oregon coast at Coos Bay, diminishing the extent of active dune sands and encouraging the formation of foredunes and deflation plains (left - 1939, right - 1975). (Photos courtesy of U.S. Army Corps of Engineers, Portland District.)

C. Older Vegetated Dunes

The active dune fields found on the Oregon coast achieved their present development during the last few thousands of years as the sea rose to its present level. Cooper (1958) discusses the abundant evidence that a similar history of dune development occurred earlier during the Pleistocene, also at times of submergence (times of glacial melting). There appears to have been at least two such episodes of dune formation on the Oregon coast. The dune fields formed during these earlier episodes are now generally well vegetated with forests of pine and spruce and with at least some soil development. They vary considerably in the amount of cementation of the old dune sands beneath the soil cover. Although vegetated forms of transverse-ridge and oblique-ridge dunes cannot be recognized, vegetated precipitation ridges provide good evidence for the landward extent of the old dune fields.

Most of these older dune fields are adjacent to important bodies of modern dunes, indicating that in the earlier cycles, dune development followed processes similar to those of the present fields. Particularly large areas exist to the east of the active Coos Bay dune sheet, especially to the north of Florence and to the immediate north of Coos Bay. Portions of these old forested dunes are also found on sand spits such as Bayocean and Netarts, and in terrace areas such as around Newport. Cooper (1958) provides a series of maps showing the aerial extent of the old vegetated dune fields.

Where these old dune sands are uncemented, removal of the vegetation cover can result in their rejuvenation. Natural examples of this are commonly found adjacent to the beaches where wave erosion cleared some of the dunes of vegetation. This leads to a blowout, removing dune sands from the exposed portion. If the effective wind is unidirectional, then the blowout can develop into a parabola dune, a trough blowout of major size with large terminal and lateral walls. Parabola dunes grow progressively in length in the direction of effective wind, and more slowly in width. According to Cooper (1958, p. 75), most have developed in areas protected from the summer winds and are hence mainly under the influence of the winter's southwest winds. For this reason, most develop northward to northeast. In addition to originating near the beach, a number of parabola dunes have also formed along the margin of the Coos Bay dune sheet. The extensive field of active dune sands to the north of Sand Lake is basically a large parabola dune, the largest on the Oregon coast (Cooper, 1958, p. 75). Although these examples of parabola dunes were formed naturally, man's removal of the vegetation covering the older dunes can similarly bring about rejuvenation and the development of a blowout or parabola dune.

The Clatsop Plain extends from the Columbia River south to Tillamook Head, and is largely covered by a series of vegetated dune ridges. These dune ridges are long linear features extending approximately north-south, roughly parallel to the modern-day beach. Long linear lakes, marshes and creeks occupy the lows between the dune ridges. The vegetation cover of the Clatsop Plain has undergone extensive changes in the last 100-150 years; these changes are documented by Hanneson (1961, p. 85).

Although vegetated, the dunes of the Clatsop Plain are not as old as the other vegetated dunes discussed in this section. They were formed during the last several thousand years as the sea neared its present level. Following sea level rise, the beach built out and the dune ridges developed on the accreting land, formed by the abundant sand supplied by the Columbia River. Cooper (1958, p. 123-6) recognizes three stages of progradation on the basis of three groups of ridges. Shoreline advance appears to be continuing, although the picture has been somewhat complicated by the construction of the jetties at the mouth of the Columbia. Dicken (1961, p. 73) calculated, for example, that the maximum growth of the beach between 1944 and 1960 was about 500 feet, some 30 feet per year. As discussed in Section V, the excess of sand at Seaside has resulted in problems with blowing sand, and several hundred thousand cubic yards of sand have been removed from the Seaside beach since 1960 (Stembridge, 1975, p. 45).

Beneath their vegetative cover, the dune sands of the Clatsop Plain are loose. As already discussed for the older dunes of the Oregon coast, removal of the vegetation cover can lead to blowouts and dune rejuvenation.

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